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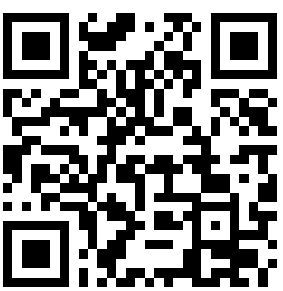

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FUNDAMENTALS OF RADAR

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US NAVAL AIR TECHNICAL TRAINING CENTER,
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FOREWORD

The primary objective in presenting a course in Radar Fundamentals is to provide the student with an adequate understanding of the circuits fundamental to all Radar equipments, in order that he can develop an overall picture of Radar requirements and performance. The student should be conditioned to accept instruction in the various specific types of Radar, retaining his concept of the overall basic requirements, without becoming confused by design characteristics or minor variations in fundamental circuits performing special functions.

The material composing "Fundamentals of Radar" has been compiled by the Instructional Staff of the Radar Fundamentals Section, Naval Air Technical Training Center, Corpus Christi, Texas. Its purpose is to furnish a source of information to which the student may turn in preparation for the specific lectures presented in Radar Fundamentals, and to provide a ready reference to basic circuit analysis as he progresses through the course of training at this center.

Close agreement is maintained in the sequence of articles in the pamphlet and that of the lecture material presented in the Radar Fundamentals course. In the preparation of the various articles a consistant effort has been put forth toward the development of a standard nomenclature based on the terminology exercised in Appendices A and B.

The data tabulated in Appendix C is presented as a further effort to impress the student with the scope of application of the circuits he is studying in the Fundamentals section. Appendix D embodies supplementary material included to assist in effecting the transition from the study of basic Radar to that of specific types of equipment. Appendix E lists the recently adopted Army-Navy nomenclature.

26045

Particular credit is due R.E., L. H. Parks, USNR and H. A. Owen, ARTlc, USNR, who carried out the greater portion of the detail involved in the development of this pamphlet. The organizational work and editing was done by Lt. (j.g.) John E. Williams, USNR.

A. J. Beaudoin
Lieut., USN
Supt. of Training

Approved:
G. K. Stoddard
Comdr., USN (ret)
Commanding

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CHAPTER I

Basic Concepts of Radar Performance

1. RAdio Detection And Ranging (RADAR) is the art of locating by radio means the presence of objects, determining their present angular position (bearing) and range, and recognizing their character; and of utilizing the data thus obtained in the performance of military and Naval action.

2. In order to accomplish this detection and ranging a beam of R.F. energy is directed over a region in search of a target. If the beam strikes a target the R.F. energy is reflected, some small portion of which will travel back in the direction of the transmitter. A receiver is located in the vicinity of the transmitter capable of detecting this reflected energy (echo), together with a time measuring device capable of indicating the extremely short lapse of time between transmission and reception. Knowing the velocity of propagation of the R. F. energy the lapse of time between transmission and reception indicates the range of the target. The mere fact that an echo returns reveals the presence of the target.

3. Three systems have been developed as a means of enabling the receiver to distinguish between the R.F. energy being transmitted and that being reflected from a target.

(a) The Frequency Modulation system requires that a R.F. carrier be continuously varied over a certain range. As a period of time elapses between the transmission and reception there will be a frequency difference between the transmitted R.F. and the reflected R.F. at any instant. This difference frequency (beat note) if present reveals the presence of a target and the frequency of the beat note reveals the time difference between transmission and reception, thus the range. This system is applicable to fixed targets only as is evidenced by a consideration of the Doppler Effect.

(b) The C-W system is applicable to the detection of moving targets, as an unmodulated R.F. carrier is transmitted and the system depends upon the shift in frequency due to the Doppler Effect to indicate the presence of moving targets. Stationary or slow moving targets or those having slight relative motion would not be detected.

(c) The Pulse-Modulation system has by far the greater application and is undergoing more rapid development and wider use. Here the transmitter is turned off before the reflected energy arrives back from the target. The receiver has no trouble in distinguishing between the two signals as only one is present at a time. The sequence of events is as follows: The transmitter is turned on, allowed to remain on for a very short time and then turned off. After the reflected signal is received and indicated the transmitter is turned on again and the cycle is repeated. It is seen then that the transmitter sends out short bursts or pulses of R.F. energy. The receiver detects the echoes of these pulses when they are reflected from a target.

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4. Direction and distance finding by use of echoes is by no means new. The process has been in continual use since some savage in his bark canoe shouted and listened for the echo from a nearby cliff. It has been demonstrated that bats emit short bursts of supersonic energy as a means of detecting and ranging on objects. Modern science has adapted echo ranging to under-water sound. In all these systems a short sharp pulse of energy is emitted; it travels to the target, is reflected, and travels back again. By listening for the echo certain information may be obtained -- since the echo returns from the target, the direction of return must be the direction of the target; and since the energy travels at a known velocity, the time from the transmission of the pulse to the reception of the echo is an indication of the distance to the target. The underwater sound system has retained its merit due to the fact that the velocity of sound in water approaches one mile per second and the speed of surface or a submerged vessel is quite slow in comparision. However, considering that the velocity of sound in air is approximately 1100 feet per second, a modern plane traveling in excess of 300 miles per hour, or approximately 450 feet per second, might well be past and out of range before any effective action could be taken against it, if a sound system were relied upon.

5. In the past the Navy has depended for its direction and range data on optical equipment. The visual system is limited by the distance one can see or the "line of sight". On a clear day the optical range-finders of a battleship have a range of from 18 to 20 miles. This distance can be and is usually increased by use of scouting planes in directing the fire of the guns. Naturally at night and on a foggy day the usefulness of the optical equipment is practically nil, and since planes cannot fly in all weather their usefulness is likewise restricted.

6. By considering the shortcomings of the older types of detection or ranging it can be seen that the modern system must have a sufficient range to be effective against aircraft, must be equally efficient day or night (or in foggy or cloudy weather), must possess a high degree of accuracy, and must be capable of being used on land, at sea, or in the air. The pulse modulation system is designed to meet these requirements and consists of (1) a source of powerful R. F. pulses of short duration, i.e., a transmitter and a directional radiator, (2) a receiver of great sensitivity, and (3) a means of indicating the required data. The discovery of this principle dates back to the early days of radio when it was discovered that the ionosphere was reflecting radio waves and thereby the height of this layer could be measured. Presumably all the technical laboratories of the great military powers recognized the importance of this discovery and immediately set to work developing it for some practical military use. The English physicist, Professor Watson-Watt, has stated that English research on Radar started in 1932. The development of the modern cathode-ray tube at about this time gave momentum to the research as it became evident that a cheap and reliable indicator or time measuring device had become available.

7. A crude form of radiolocation of Soviet origin appeared in the Spanish Civil War on the Loyalist side. Also reports from U. S. intellignece officers indicate German trial of the principle in that same test war. However the real test of radiolocation did not come till the

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war between Germany and the democracies got underway.

8. The first real indications of the usefulness of radio-location came with the finding of the German prison ship Altmark and the defeat of the numerically superior Luftwaffe by the Royal Air Force during the battle of Briton, both being almost totally due to the use of Radar. Until the case of the Altmark, the English land stations which are placed all along the coast of Great Britain, had been having great success in accurately locating enemy planes attempting bombing raids. However the policy of the RAF had been to dispense with so called frills and put as much armament as possible in each plane. So that without positive proof of the usefulness of radio-location on planes the finding of the enemy was left much to the sight of the observer. Part of the coolness to radio-location was also due to lack of experience and incorrect or faulty installation of the gear.

9. In April 1940 the German prison ship Altmark was sighted by several English destroyers. After a chase which took them to the coast of Norway the English lost contact. However all information was made available to the Coastal Command of the RAF and a search was started by several of the Radar enthusiasts of the High Command. Using an early model of ASV (the latest at that time) they fitted out a patrol plane and went in search of the vessel. As the plane was flying past one of the numerous fjords of Norway it was noticed that a large blip of very short duration appeared on the ASV indication unit. On turning around and flying past the fjord again the same indication was noticed. The pilot was instructed to turn inland and fly up the fjord. There, out of sight from the sea, lay the Altmark. Immediately the Royal Navy was notified. After the Altmark incident, aviation radio-location was accepted as a proven weapon of great worth and it is widely used in the RAF today. However even a greater indication of its use was the application of Radar to night fighting.

10. If a pilot on a clear day is informed by radio from the Radar station in his area of the presence of enemy planes at a certain point, he can proceed to that place and make contact visually. But if it is at night or in foggy or unclear weather (such as is encountered often in England) the pilot can only trust to luck even though directed to within several miles by the ground station. So a system was evolved whereby the ground station directed the pilot to within a certain range, after which a Radar device in his own plane put him right on the enemy planes. Thus, the English were able to counter the night bombing which the Germans turned to after being defeated at day bombing. Of course the development of this interception or AI equipment required that some means of swift identification of the plane as friend or foe, called I.F.F.

11. As the war has progressed, so has the development of radio-location. The success of the Bismark in sinking the Hood is attributed by most experts to the use of radio-location for range finding. And official reports of the British Admiralty admit that if their radio-location range finder had been relied on rather than the optical system the outcome would have been much different. The unheeded warning of Sgt. Lockhard at Pearl Harbor was based on indications received on Radar equipment. The reports on Japanese activity in the Far East are rich with accounts of the reliance on radio-location.

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Mention of this is most notable in the accounts in Life of May 11, 1942 on pages 10 to 14, by Cecil Brown.

12. On the English front the achievements of radio-location have been many. In mastering the German Luftwaffe so that the raids over England have been cut to a few nuisance raids the RAF attributes much of its success to the "smeller" as it was affectionately called by Winston Churchill. This is the AI mentioned earlier. The latest issue of Janes Aircraft of the World also acknowledges the increasing role played by radio-location in combating the Nazi raiders. The development of new types of anti-aircraft using radio-location devices for training the guns also is contributing to the wariness of the Luftwaffe over England, However, good must be taken with the bad and since the Germans have had long experience at war it would seem natural to find them making use of the principles. Commando raids have been carried out for the sole purpose of destroying German radio-locator stations. The raid at Dieppe will be recalled, which really was a practice for the gigantic task of invading Europe. One of the primary tasks of that raid was the demolition of Nazi radio-location stations used to detect convoys in the Channel.

13. To date reports from the Pacific-Far Eastern war area indicate a great use of Radar and an equally great gain from its use. The reports of Patrol squadrons of all types indicate a wide use of Radar and a correspondingly great gain from its use. Also, the shipboard equipments have given good accounts of themselves. One particular section where Radar has increased the effectiveness of operations is the Alaskan area. It has been reported that Radar, used for location and navigation, has increased the effectiveness of aerial operation in this area by 75%. Since the weather is very foggy and stormy it can be seen that many days would be unfit for flying. However, with Radar on the plane, used both for location and navigation, flying is possible approximately 95% of the time. It is interesting to note some of the ranges obtained with ASE installations in the Alaskan sector. The following results are common: Destroyers and like sized ships, 18 to 25 miles; aircraft and larger ships such as transports, 30 miles; aircraft carriers, 50 miles; mountains, 90 miles. Since many mountains are on islands and rise out of the sea abruptly to heights of around 7500 feet or more, navigation without Radar in any but clear weather would be impossible.

14. In the battle of Midway a large Jap task force was approaching the island presumably to attempt occupation. At the island at that time were several squadrons of land based bombers. Also in the vicinity was the carrier Yorktown. Without Radar a continuous patrol depending on visible detection would have been necessary. With Radar the enemy was detected some 100 miles away and his course plotted. After allowing the Japs to close in (thus saving fuel) the carrier planes and the land-based bombers were sent to the attack. Directed by the large Radar stations on the carrier and on Midway our pilots knew just where to go. Thus a much weaker force in numbers was able to disperse and defeat the superior Jap Force.

15. Evidently the Japanese have radio-location gear as is evidenced by such antennas on their ships but either do not have good equipment or do not use it properly. U.S. submarines

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fitted with special receivers to pick up the signals from radio-location transmitters have scouted the coast of Japan without success. In the battle against the submarine it is apparent that Radar is the best weapon available. A patrol plane can go out at night and very quickly spot a sub which in day time would remain submerged.

16. Today Radar is playing a great role in the conduct of the war, especially against the submarine. First mention of the use of radio-location on Flying Fortresses and other large planes was made in several issues of Fortune in early 1942. And the Germans are making use of the principle in development of anti-aircraft to combat United Nations bombers. Their well-known Flakturm or anti-aircraft tower makes use of a radio-location-predictor to determine the range of attacking planes. The English are also using the same principle and attaining success with it. Latest indications are that tanks will be fitted with the Radar system to make them more effective. Thus it can be seen that probably all of the great powers are using the principle of radio-location in some manner and that its success in helping win the war depends on our development of better equipment and the keeping of its secrets of operation from the enemy so that he cannot develop a counter-weapon to our Radar.

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CHAPTER II

Power Supplies

1. Necessity for Various Types of Power Supplies: In Radar, there are numerous applications of various types of power supplies, since there are different power requirements throughout the equipment, such as light weight, high efficiency, good regulation, etc. It is doubtful that any one power supply could meet all these requirements, therefore several types are used in each Radar equipment. For example one requirement may call for an output in the order of + 15,000 volts, with voltage regulation being of small consideration; while another supply may be required with an output of -1300 volts, with much regard toward excellent voltage regulation. It can be seen, therefore, that different supplies are needed to meet different requirements and must be designed accordingly.

2. Size and Weight Requirements: Two of the prime considerations in the design of equipment for use in aircraft are size and weight. Space and weight carrying ability are both necessarily limited in the airplane, and they must be utilized to the best advantage. As is well known, the power supply contributes a large part of the weight of any but the small AC/DC receivers. This weight must be reduced to a minimum in aircraft Radar equipment. The basic design formula for power transformers is

$$E = 4.44\ BANf \times 10^{-8}$$

where E = voltage
A = area of core
B = flux density
N = number of turns
f = cycles per second

The weight of the core, and its size, depends on 'A'. The weight of the copper windings is dependent on 'N'. If these two factors can be reduced, the size will be reduced.

3. Since the product of the terms B, A, N, and f is multiplied by a constant to give voltage, any of these four factors may be reduced if another is increased to make the product the same. Both 'N' and 'A' should be made as small as possible. 'B' is determined by the type of iron used, and can not be changed at will. However, 'f', the remaining factor, can be easily increased. Most of the aviation Radar equipment has been designed to operate at supply frequencies of about 800 cycles per second. With this high supply frequency, not only can the size and weight of the transformers be reduced, but drastic reductions in the size and weight of filters may be effected.

RECTIFIERS

4. The first thing required in a system to change AC to usable DC is a rectifier. A rectifier is a device which will allow current to flow through it in only one direction. Rectifiers used in Radar usually take the form of high-vacuum diodes.

5. When the cathode of a tube is heated, electrons are driven out of it and into, the surrounding space. If the plate is made positive with respect to the cathode, these electrons, since they bear a negative charge, will be attrac-

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ted to this plate. The flow of electrons from cathode to plate constitutes a flow of current. Now, if the plate is made negative, the negatively charged electrons will be repelled, and no current will flow.

6. Half Wave Rectifiers: Figure 1 shows the effect of applying an alternating voltage to this simple diode. At 'A' there is no difference of potential in the circuit, so there is no current flow. At 'B' the plate has become positive with respect to the cathode. This means that current is flowing through the circuit, producing a

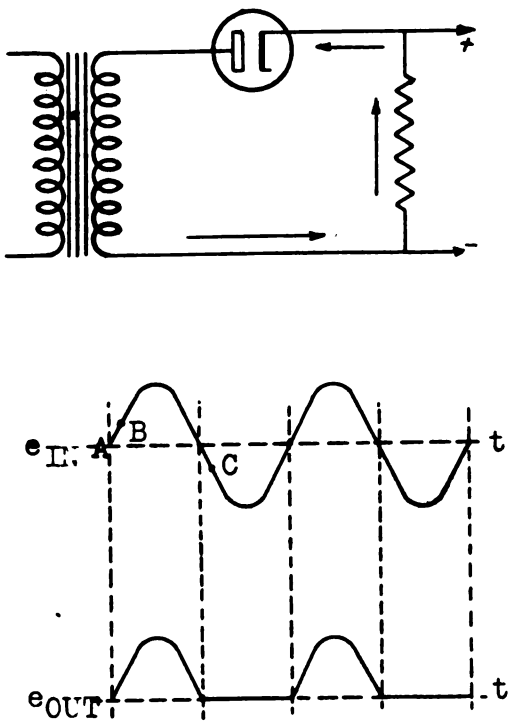

Fig. 2-1: Half Wave Rectifier.

voltage drop across the load resistance. The current (electrons) flows through the circuit in the direction of the arrows, through the tube from cathode to plate, and the polarity of the voltage drop across the load is such that the aathode termination is positive.

7. At point 'C' the voltage has passed through its positive maximum, back through zero to a negative value. With the plate now negative with respect to the cathode no current can flow through the tube. Since the tube is in series with the transformer and the load, no current can flow through the load, and there will be no voltage drop across the load. So far as output voltage and current are concerned, everything below the zero line can be disregarded.

8. The current now flows through the load in only one direction, and only when the input voltage is on the positive half of its cycle. Since current flows half of the time the average current will be a fraction of the peak current which the tube must pass.

9. Defects of Half Wave Rectifier: In studying the sine wave it is found that the peak voltage, or current, is $\frac{1}{2}\pi$, or 1,57, times the average voltage or current. But this is for only the one half cycle. If the tube is to supply enough current during conduction to make up for the non-conduction period, the peak current during conduction must be twice this, or times the average current.

10. In circuits requiring appreciable current, the half wave rectifier has another serious defect. Current through the secondary of the transformer is in one direction only. This causes DC saturation of the core due to residual magnetism, and greatly reduces the efficiency of the transformer. For high voltage, extremely low current applications such as cathode ray tube supply, or where heavy currents are drawn for short intervals of time, as in the pulsing oscillator, the half wave rectifier is frequently used. If the continuous load current becomes more than a few

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milliamperes, it is desirable to use some other circuit.

11. Full Wave Rectifier: Most objections to the half wave rectifier center around the fact that it uses only one half of the input cycle. These objections can be removed by finding some way to use both halves of the cycle.

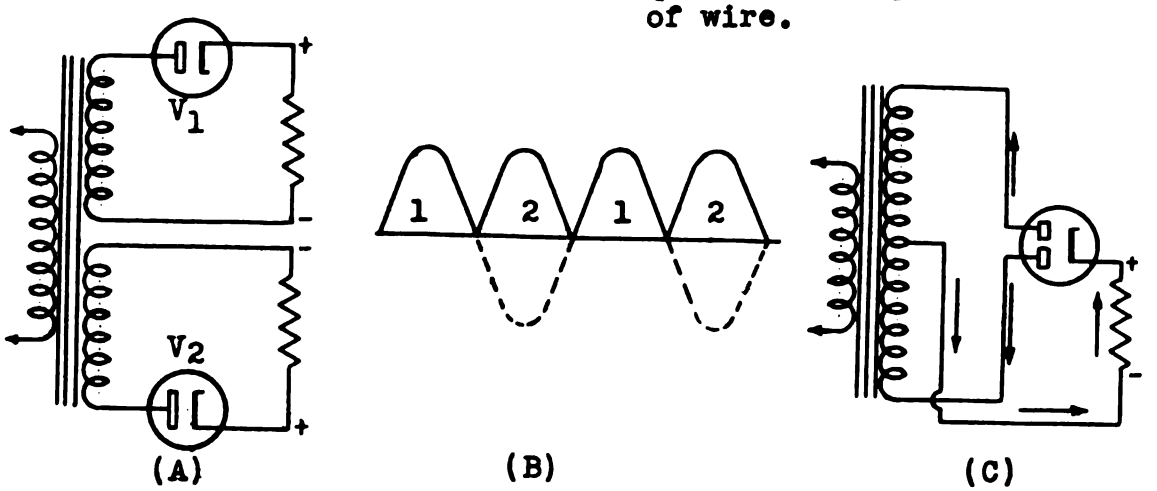

Fig. 2-2: Full Wave Rectifier.

12. If another winding, identical with the first, with its associated rectifier and load, is added as shown in Figure 2(A), and connected properly, it will be found that the plate of V_1 will be positive when the plate of V_2 is negative, and vice versa.

13. Now one tube is rectifying one half of the cycle, and the other tube is rectifying the other half cycle. Both currents flow through their loads in the same direction. The two loads may be combined into one, and the resulting load voltage will appear as the solid curve of Figure 2(B). Thus is developed the center-tap full wave rectifier.

14. In order to get full wave rectification by this means it was necessary to use twice as many turns on the transformer as was necessary for the same voltage with half wave rectification. This means extra size, weight and cost. At comparatively low voltages, such as used for receiver power supplies, this extra winding is not particularly objectionable, and the advantages of the system outweigh its disadvantages. At high voltages, however, where the winding requires several thousand turns of wire, it is desirable to use some system which does not require the large number of turns of wire.

15. Bridge Rectifier: One such system is the bridge rectifier shown in Figure 3.

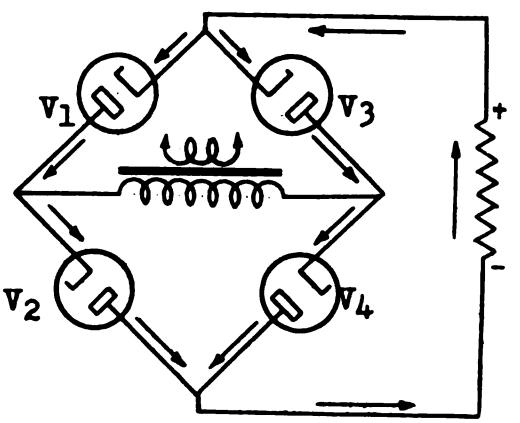

Fig. 2-3: Bridge Rectifier.

Starting at the moment when the right hand end of the transformer is positive, the current flow will be as follows: Current will flow down through V_2 up through the load, and back the positive end of the transformer through V_3. On the next

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half-cycle the right hand end of the secondary is negative. Current will now flow down through V4, up through the load, and back to the positive end of the transformer through V_1. On both half cycles the current flows through the load in the same direction, so full wave rectification is obtained.

16. Copper Oxide Rectifier: The contact rectifier, commonly known as the copper oxide rectifier, is a low voltage rectifier which is ordinarily used in a bridge circuit for full wave rectification. In this general class are the copper oxide rectifier, and the selenium rectifier. These rectifiers are used where a high current and comparatively low voltage are required. The circuit is shown in Figure 4. In the case of the copper oxide rectifier it is found that electrons will travel from the copper to the oxide films about a thousand times more easily than from the oxide to the copper.

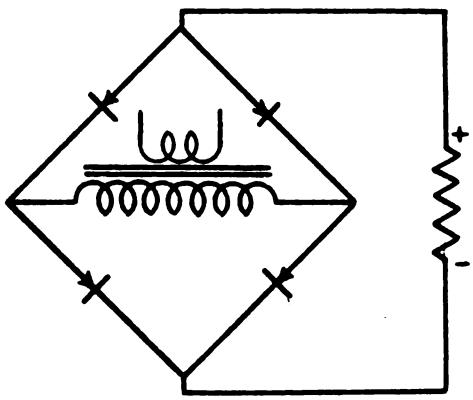

Fig. 2-4: Copper Oxide Rectifier

Thus, though there will be some current in the reverse direction it will be so small in comparison to the current which passes through the rectifier in the forward direction that it may be neglected.

17. Voltage Doubler: When requirements call for a very high voltage at low current the voltage doubler is usually employed. A voltage is obtained, using a given transformer, which is twice the value obtained by half wave rectification and four times the value obtained by center tap full wave rectification..

18. Figure 5 is a diagram of a full wave voltage doubler rectifier. This circuit is very widely used when it is necessary to supply several thousand volts at low current. The action of the circuit is as follows:

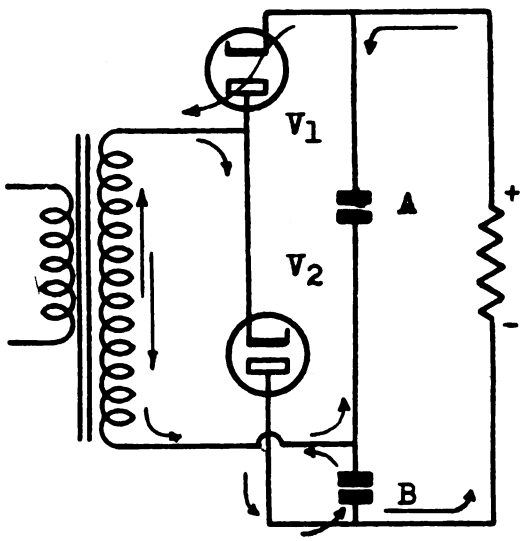

Fig. 2-5: Voltage Doubler.

When the upper end of the transformer is positive, electrons will be drawn away from the upper plate of condenser 'A', through V_1 and the transformer, and piled up on the lower plate of condenser 'A'. Since the RC time of this charge path is short, the condenser will be charged to the peak voltage of the transformer.

19. During the next half cycle the lower end of the transformer is positive. Electrons will now be drawn from the upper plate of condenser 'B', through V_2 and the transformer, and will be piled up on the lower plate of condenser 'B'.

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This action will charge condenser 'B' to the peak transformer voltage. The two condensers, each charged to the peak transformer voltage, are connected in series across the load. If the condensers are large compared to the load, so that their discharge between cycles is small, the output voltage will approximate twice the peak transformer voltage. Since at least half of the output current is being supplied by a condenser at all times, the voltage regulation of a voltage doubler is inherently poor.

20. The higher the capacity of the doubler condensers, the better the regulation will be, but besides the difficulty of making high capacity, high voltage condensers, there is the additional trouble in that the high capacity condensers will make the tube's peak plate current extremely high.

supply. V_1 operates as an ordinary radio frequency oscillator, working at a high frequency. The RF output is fed to a Tesla coil which steps it up to a very high voltage. The output of the Tesla coil is rectified by an ordinary half wave rectifier, (V_2), filtered, and used to supply the intensifier anode voltage to the cathode ray tube.

CRO POWER SUPPLIES

22. Each of the rectifiers mentioned has its particular field, to which it is well adapted. In other applications it may be useless. Frequently, and especially in work with cathode ray tubes, it is found that there is more than one field of service represented in one piece of apparatus. A combination of rectifiers, each suited to its particular task, may be used to fill this need.

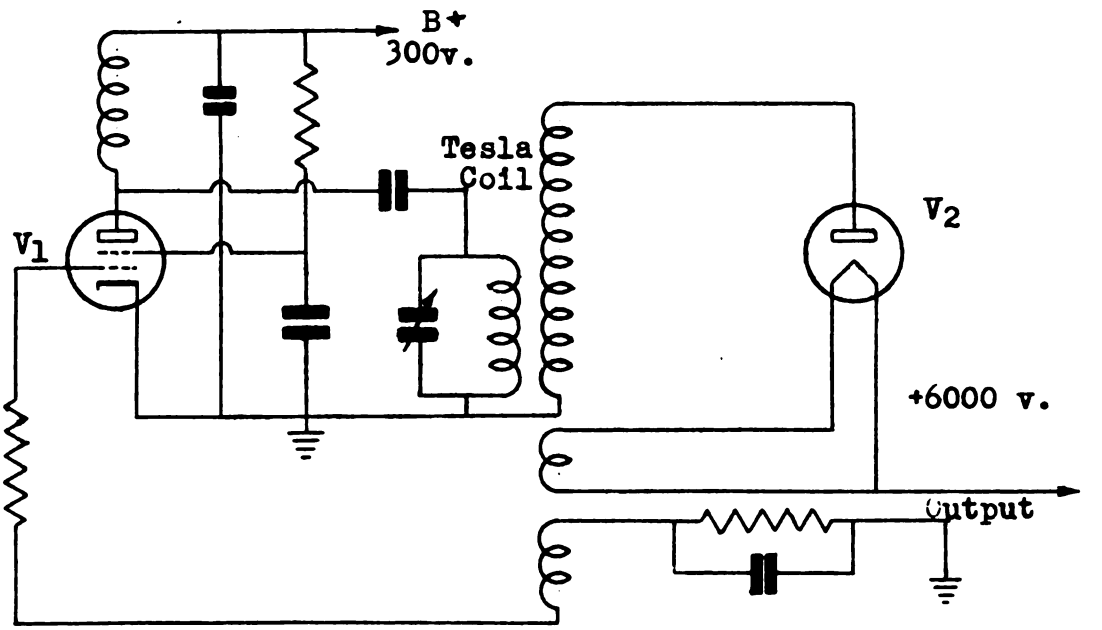

Fig. 2-6: High Frequency Power Supply.

21. High Frequency Power Supply: Figure 6 illustrates an interesting way of obtaining extremely high voltage-low current supply for cathode ray tube power

A typical power supply for cathode ray oscilloscopes is shown in Figure 7.

23. Sweep circuits and am-

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plifiers in the oscilloscope require a medium voltage and a relatively high current. The center-tap full wave rectifier can easily supply this need. However, the cathode ray tube requires a high voltage at a very low current. Here the full wave rectifier would be wasteful, but the half wave rectifier is ideal.

POWER SUPPLY FILTERS

24. The voltage obtained from the various rectifiers, although it is DC because it flows in only one direction, is far from the pure DC needed for plate supply. It may be thought of as direct current with a high value of alternating current.

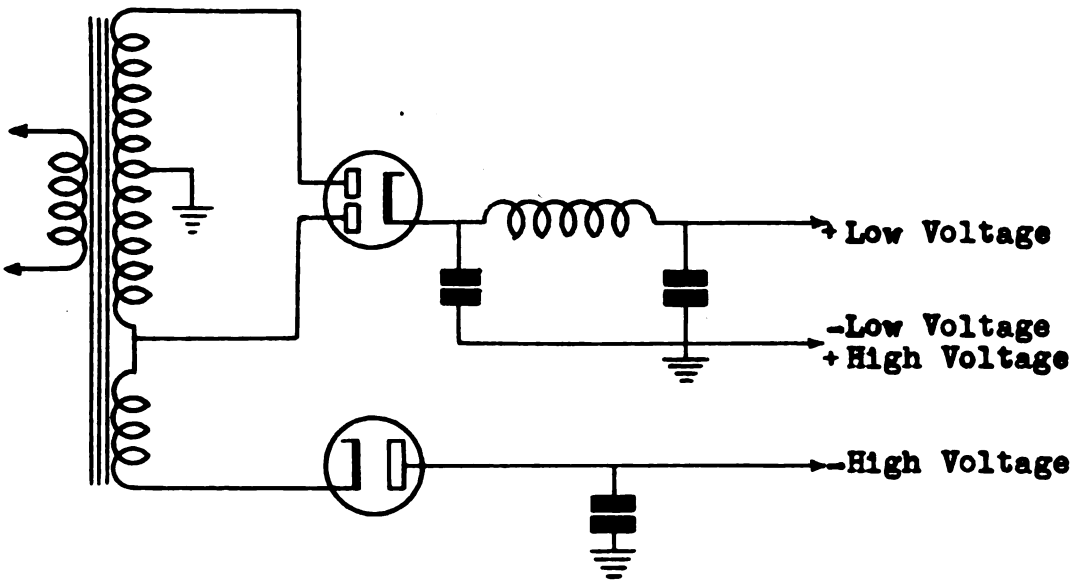

Fig.2-7: A typical CRO Power Supply.

The two are combined as shown. A center tapped winding is used for the full wave rectifier. Half of this winding, plus an additional high voltage winding, is used for the half wave rectifier. Since the deflection plates of the tube are returned to the highly positive second anode it is necessary, for purposes of safety, to put this voltage at ground potential. The cathode of the tube is highly negative with respect to ground, while the anode is placed at ground potential, so the same difference of potential exists in the tube as would exist if the cathode were placed at ground potential and the anode operated at a positive potential.

superimposed as ripple. This ripple has a fundamental frequency equal to the supply frequency in the case of half wave rectifiers, and twice the supply frequency in the case of full wave rectifiers. Since pure DC is desired, at the output of the power supply, the ripple must be moved.

25. If the output current is low, a single condenser will do a fairly good job of filtering. When current is flowing through a diode, the diode acts exactly like a low value of resistance. Thus when the upper end of the transformer (Figure 8) is positive with respect to its cathode,

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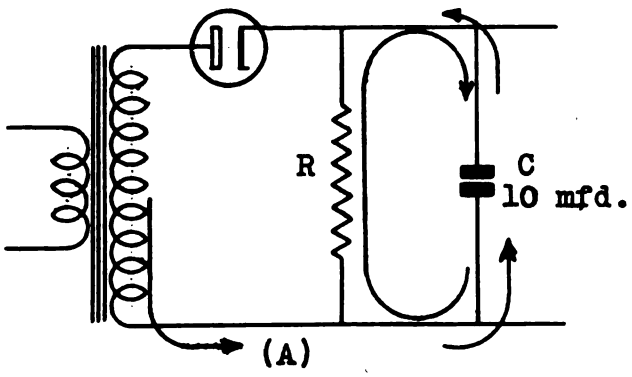
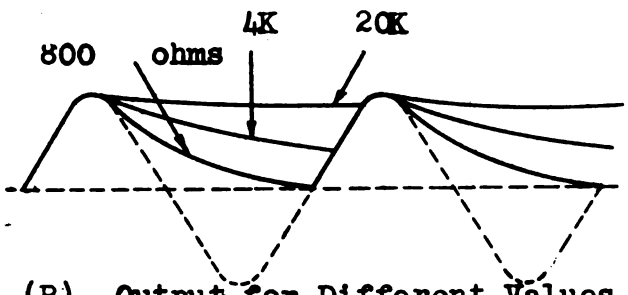
current flows through the circuit, charging the condenser to the peak transformer voltage through a short RC. The upper plate is connected directly to the cathode of the rectifier. The condenser is charged so that the upper plate is positive. Now when the transformer voltage starts to decrease, removing the charging voltage, the condenser tends to discharge. It cannot discharge through the tube, since electrons cannot flow from plate to cathode. The only discharge path is the relatively long RC path provided by the load resistance.





(B) Output for Different Values of R.

Fig. 2-8: Filtering Effect of a Single Condenser.

26. Since the condenser cannot discharge rapidly, and its positive plate is connected to the cathode of the diode, as soon as the transformer voltage starts down, decreasing the plate voltage, the cathode becomes positive with respect to the plate. There will be no further current flow through the tube until the transformer voltage has passed through its negative maximum and has again become more positive than the cathode. The voltage appearing across the load for several different values of R is shown in Figure 8 (B). It can be seen that for a given capacity, as the load is increased by decreasing the effective resistance, the ripple voltage becomes higher and the effective voltage becomes lower.

27. The filtering effect can be increased by inserting a resistor in the charging path of the condenser. The effect is shown in Figure 9. Both charge and discharge now take place through long RC paths. Since the DC value is dropped, as well as the AC, the condenser-resistor filter is practicable only when the load current is low. Otherwise there is an excessively high DC voltage drop across the filter resistor.

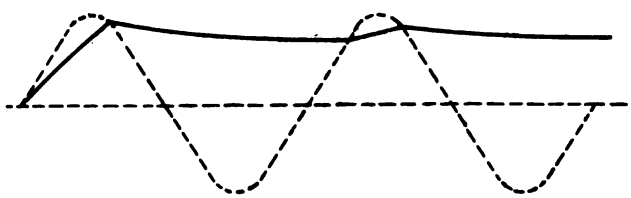


Fig. 2-9: Output of a Condenser-Resistance Filter.

28. L - C Filter: An inductance has the property of opposing any change in the amount of current flowing through it. Any attempt to increase or decrease the current is met by a counter voltage set up within the inductance. If the load on a power supply is constant, any change in the voltage across it must result from a change in current through it. If the current is held constant, the voltage

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will be constant. Therefore a choke may be used to smooth the output of a power supply. By using a combination of series chokes and parallel condensers, as shown in Figure 10, the ripple voltage may be decreased to a very low value.

29. Considering only the AC ripple voltage, it may be said that the inductance provides a very high impedance, while the condenser provides a very low impedance. The combination may be considered as a voltage divider. Naturally, most of the ripple voltage appears across the high impedance. A two section filter would appear as shown in Figure 10(B). The impedance of the series section of the filter may be increased by tuning the choke to parallel resonance. This means it is impossible to get much higher impedance with the same choke, or the same impedance with a much smaller choke. It is also possible to decrease the shunt

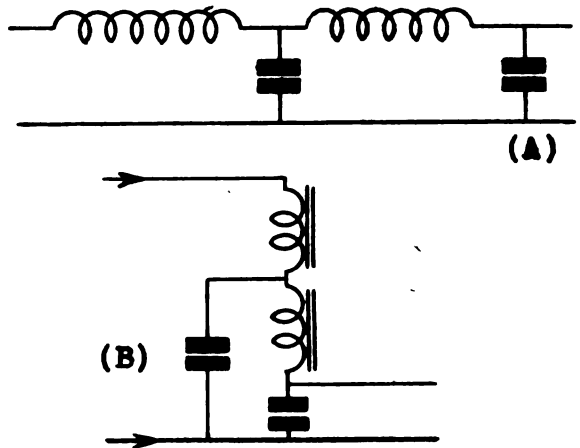

Fig. 2-10: Low Pass Filter

impedance by tuning the condensers to series resonance. Two types of Resonant filters are shown in Figure 11. They are rarely used since their tuning depends on the load current, and excellent filters which stay good over wide ranges of load current can easily be made by using larger components. At voltages for which electrolytic condensers are not available or too bulky, the resonant filter may be used to obtain the maximum filtering from low capacity paper condensers.

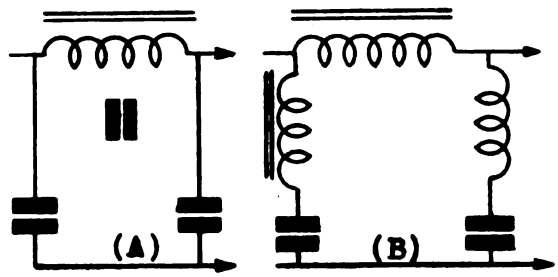

Fig.2-11: Resonant Filters.

VOLTAGE REGULATORS

30. It is sometimes necessary that constant voltage be applied to a circuit. When this is the case some type of voltage regulator is used.

31. Gas Tube Voltage Regulator: The circuit employing a gaseous diode represents the simplest type of voltage regulator and is shown in Figure 12. The series resistor is a part of the circuit and must be used.

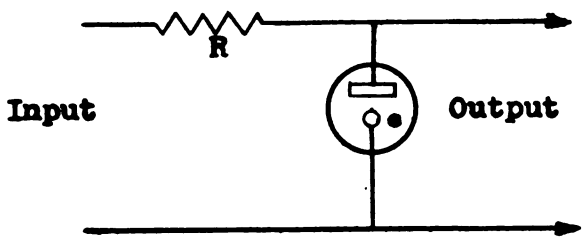

Fig. 2-12: Simple Voltage Regulator.

32. If a voltage is applied across the circuit, starting at a low value and gradually increasing, it will be found that the voltage across the gasdiode increases until a certain voltage is reached at which the gas ionizes. If a meter were placed in series with the tube it would be found that no current would flow through the tube until the critical voltage is reached.

33. As the degree of ionization of the gas within the tube as a function of the voltage across the tube, it follows

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that any slight rise in voltage would increase the ionization, thus decreasing the resistance of the tube. The increase in current flow is proportional to the decrease in resistance, therefore the voltage across the tube will remain constant. However, the series resistance is fixed in value and the increased current through it will produce a greater IR drop. Therefore, any voltage variations occuring in the circuit will appear across the series resistance and not across the gas tube.

34. The VR150-30, VR105-30, and VR75-30 are gaseous tubes often used in voltage regulator circuits. The voltage drop across these tubes is constant over a moderately wide current range. The first number in the tube designation indicates the terminal voltage, the second number indicates the maximum permissible current in milliamperes which may be passed by the tube. In the case of the above named tubes, the voltage required to start the tube is normally about 30% greater than the operating voltage. In order to maintain stable operation, a minimum current of 5 to 10 milliamperes is required to flow through the tube. Since the maximum current should not exceed 30 milliamperes, it may be seen that the load current should not exceed 20 to 25 milliamperes if the voltage is to be stabilized over a range from zero to maximum load current.

35. The value of resistor R in Figure 12 must lie between that which just permits minimum tube current to flow and that which just passes the maximum permissible tube current when the load is drawing no current. The latter value is the most desirable and may be found by

$$R = \frac{1000\ (E - V)}{I}$$

where R = limiting resistance R in ohms
E = voltage of the supply source
V = rated voltage drop across the regulator tube
I = maximum tube current in milliamperes.

36. The voltage of the supply source must equal or exceed the starting voltage of the tube. The difference between the supply source and the tube drop will appear across resistor R. Since the voltage of the tube remains constant, the difference between the voltage of the source and the working voltage of the tube will appear across the resistor.

37. Electronic Voltage Regulator: Electronic voltage regulation is usually used where high voltages are encountered, or where a high load current is to be used. This type of regulator may take several different forms. High vacuum tubes are usually used in these circuits and they allow the output voltage to be varied at will over a very wide range. One form of electronic regulator is shown in Figure 13. A resistor R_1 is used in this circuit as a current limiting device, and is connected in series with the tube. R_2 is a bleeder resistor

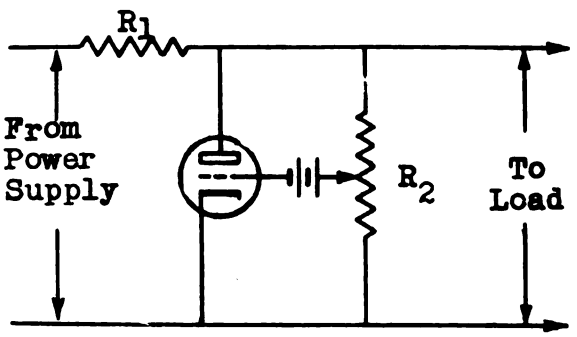

Fig. 2-13: Simple Hard Tube Regulator.

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connected across the output, and a variable bias for the tube is obtained from a tap on this resistor. The battery supplies a fixed bias to keep the tube operating over the proper part of its e_g-i_p curve.

38. When the plate current of the tube increases, the IR drop across R_1 increases, and the output voltage drops. Since the output voltage will be equal to the supply voltage minus the voltage drop across R_1 the increased drop will result in a lower output voltage. However, this decrease in output voltage will make the grid of the tube less positive, causing the plate current to decrease, which produces an IR drop across R_1 which will oppose the drop in output voltage. Likewise if the load current increases the output voltage will drop due to the greater IR drop across R_1. As a result, the grid of the tube will become less positive, or more negative, which will cause the plate current to decrease. This will cause the output voltage to be increased due to the smaller voltage drop now present across R_1. The effect of the circuit is to keep the output voltage more nearly constant.

39. Voltage Stabilizer: A variation of Figure 12, useful in removing slight transient variations, is shown in Figure 14. This circuit is a voltage stabilizer, but not strictly a regulator. Slow variations in voltage will not be affected. In Radar work the tube is frequently referred to as the "anti-jitter" tube. A resistor is again inserted in series with a vacuum tube and aids in limiting the current. However, in the circuit shown in Figure 14, the grid of the tube is connected to the input circuit, through a condenser. If ripple is present in the input circuit, the tube will remove it so far as the output is concerned.

40. If the ripple voltage should move in the negative direction, the grid of the tube will move in the negative direction, causing the plate current of the tube to decrease. This will cause a smaller voltage drop to be present across R_1, and result in an increase in the output voltage. If the circuit constants are properly proportioned, it is possible to make the amplification of the stage equal to one, or unity. This will be true when the value of the plate load resistance R_1 is made equal to $1/G_m$ of the tube. When the circuit has an amplification of 1, the voltage change at the plate will be equal and opposite to the voltage change in the grid circuit. From this it may be seen that if a ripple is present, it will be fed to the grid, and the plate will produce a voltage variation equal in amplitude and opposite in polarity, so that the ripple will be effectively neutralized. Since the effect of the cathode biasing resistor is degenerative, the value of the plate resistor must be increased to compensate for the lower effective G_m.

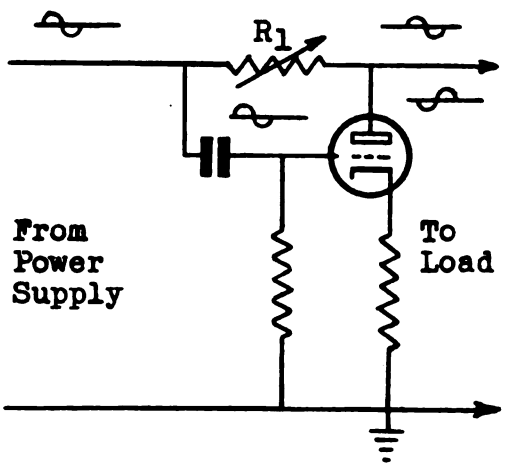

Fig. 2-14: Voltage Stabilizer Circuit.

41. Improved Voltage Regulator: Electronic voltage regulators which will cover a much wider range of current and

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voltage than the one shown in Figure 13, and which will give even better regulation of the output voltage, may be made if the single tube is replaced by several stages of amplification. One such circuit which is widely used is shown in Figure 15. This circuit is essentially a two stage inverse-feedback amplifier.

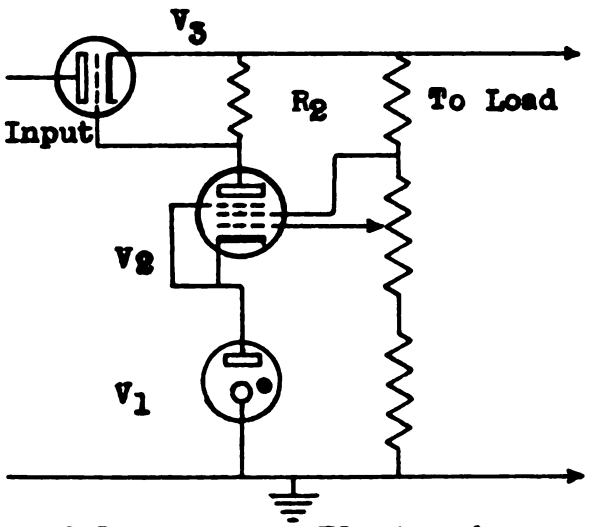

Fig.2-15: Common Electronic Regulator.

42. Any increase in the voltage to the input of the circuit will increase the voltage at the grid of V_2. V_1, a gaseous regulator tube, supplies a constant reference bias by keeping the cathode a definite voltage above ground. The increase in the voltage at the grid of V_2 increases the current through the tube, thus increasing the voltage drop across the plate load resistor R_2. This increased voltage is applied as increased bias to tube V_3. Since V_3 is in series with the load and must carry all the load current, the decreased tube current, due to the increased bias, means a decreased load current and a lower load voltage. Actually, since the increased bias was due to an increased plate voltage, the tube current remains constant, and thus the load voltage is kept constant.

43. The circuit will also keep the load voltage constant in spite of changes in load resistance. A lower resistance will mean an increase in load current, and therefore a lower voltage across the voltage divider. This will result in a decreased voltage on the grid of V_2, or the grid will be made more negative than before with respect to its cathode which is being held at a constant potential by V_1. The increased bias on V_2 will result in a decreased current flow through the plate load resistor R_2. This means less voltage drop across R_2, and therefore less bias on V_3. More current is allowed to flow through V_3, keeping the IR drop across the load constant. The output voltage may be varied at will by varying the grid tap on the voltage divider, but once the tap is fixed no reasonable change in the input voltage or load current will change the output voltage.

44. Amperite or Ballast Tube Regulator: Magnetic devices, such as the focusing or deflecting coils of oscilloscopes, sometimes required that the current through them be stabilized against changes in terminal voltage or changes in current due to the increased resistance as the coils warm up.

45. The ballast tube, or "amperite", is the simplest current regulator. This type of regulator consists of an iron wire enclosed in a hydrogen filled bulb. As the current through the wire increases, the resistance of the wire will increase rapidly over its control range. This increase in resistance is due to the temperature coefficient of the wire. In order to get good performance the wire is operated at a dull red heat. If the current is allowed to go too high, the wire will burn out. If it is allowed to go too low, the resistance

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change with current becomes too small to give effective control.

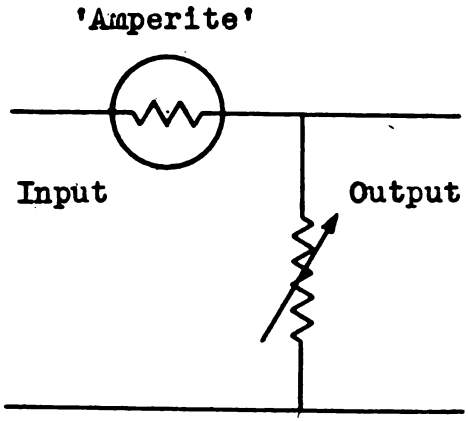

Fig. 2-16; Ballast Tube Regulator.

Over its control range, any attempt to increase the current through the regulator results merely in an increased voltage drop across the wire. One circuit, suitable for regulating the polarizing current to the deflection coils of a cathode ray tube, is shown in Figure 16.

46. Pentode Regulator: Where a relatively low current, which may be set to any desired value and held constant, is desired the constant current characteristic of the pentode tube may be utilized. A typical circuit is shown in Figure 17. The screen voltage, one of the determining factors controlling the plate current of a pentode, is held constant by means of a gaseous regulator tube. The control grid voltage, the other current controlling factor, may be adjusted by means of the rheostat in the cathode of the pentode. The degenerative effect of the cathode resistance increases the stabilizing effect by increasing the bias on the tube as the current tries to increase.

47. In any Radar equipment there are always several types of rectifiers and regulators employed, such as have been discussed in this chapter. In Figure 18, the power requirement for a typical Radar unit, including transmitter, receiver, and indicator, are listed which might apply to the systems used in any of several microwave equipments. It, therefore, does not represent any specific case, but serves as a general outline of the power needs in Radar.

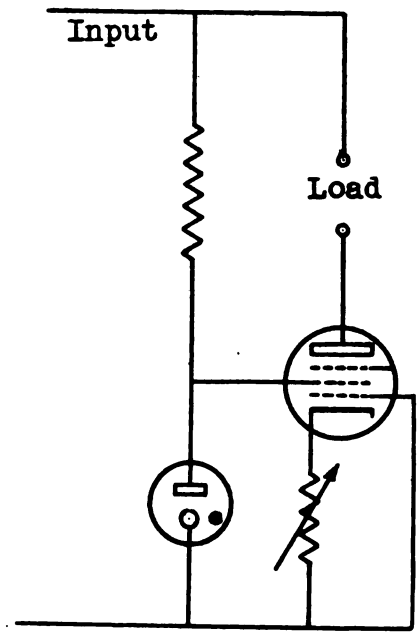

Fig. 2-17: Pentode Regulator

48. It will be seen that separate power supplies are used for different types of loads. To attempt to use only one supply for all needs would create a multitude of problems, such as reducing the voltage for receiver and indicator plate potentials, maintenance of good regulation where the transmitter current drain is not constant, and the necessity of high negative voltages as well as positive voltage.

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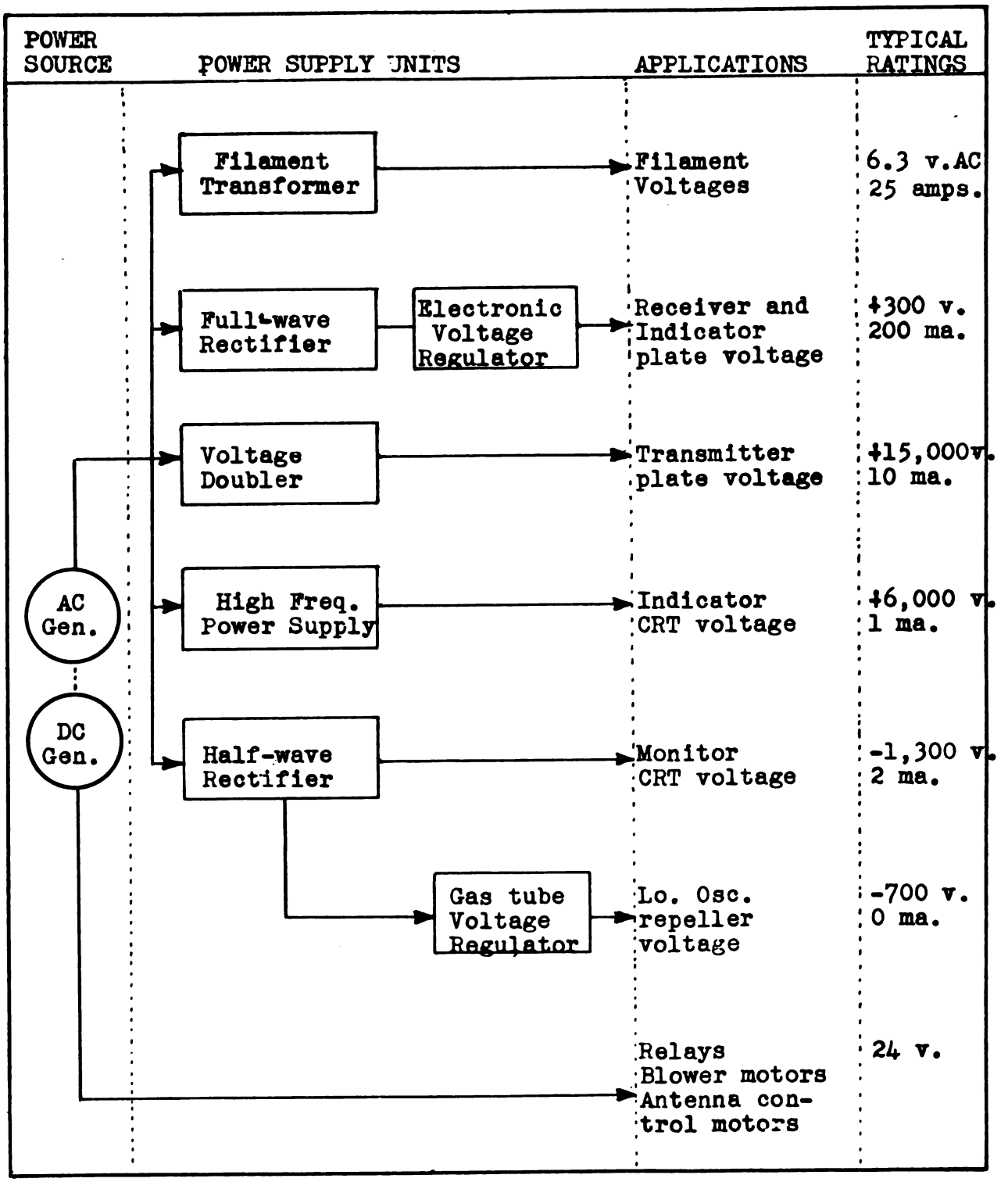

Fig. 2-18: Power Requirements for a Typical Microwave Equipment.

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CHAPTER III

RC and L/R Transients

1. The currents and voltages in an electric circuit are said to be in a transient state in the interval between a change in emf or impedance condition in the circuit and the establishment of a steady state. During this interval the currents and voltages change in value at an exponential rate.

2. In the past, the ideas of inductive reactance and capacitive reactance have been sufficient for an understanding of circuits where coils, condensers, and resistors were involved. Vector diagrams could be used then to find the current and voltage in a circuit and the phase relationship between them. It is very important to remember, however, that the term "reactance" as ordinarilly construed has meaning only when a sine wave of a definite frequency is being applied to a circuit. Suppose, for example, that a square wave of voltage is being applied to a condenser and resistor in series. It is no longer possible to say that the condenser has a certain reactance to this applied voltage. The problem must be approached from a different angle. It becomes necessary to consider the happenings from one instant to the next and for this reason an understanding of the behavior of coils, condensers, and resistors is of paramount importance. A review of the meaning of the words "voltage", "current", and "resistance" at this point will aid in understanding these behaviors.

3. Voltage: Voltage is an electrical pressure, force, or stress, acting in an electrical circuit just as a mechanical force acts in any mechanical device. Remember that forces can exist without any motion taking place. If one pushes against a wall, he is exerting a force, but no motion is taking place. Likewise, there is an electrical force (measured in volts) between the two terminals of a battery, but no motion of electrons will take place unless a path for their flow is provided.

4. Current: If a path is provided, perhaps by placing a resistor across the terminals of a battery, current will flow. The term "current" deals with the motion of electrons. It is a measure of the rate of electron flow. One coulomb (6.24×10^{18} electrons) flowing past a point in a circuit per second constitutes a current of one ampere. One of the most important facts about current is that electrons flow as if they constituted an incompressible fluid. In other words, at any given instant the current is the same in all parts of a series circuit.

5. Resistance: Resistance is electrical friction. It is the property of a conductor which limits the amount of current flow a given voltage will produce. All conductors possess some resistance, but when a device is made especially with the idea of limiting current flow, it is called a resistor. A resistance of one ohm will allow a current of one ampere to flow through it when a pressure of one volt is applied ($I = E/R$).

6. Kirchoff's Second Law: Kirchoff's laws are a direct

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result of the definitions just made. The second law, which states that the sum of the voltage drops and electromotive forces (sources of pressure) in a closed circuit is at any instant zero, is of the greater concern here.

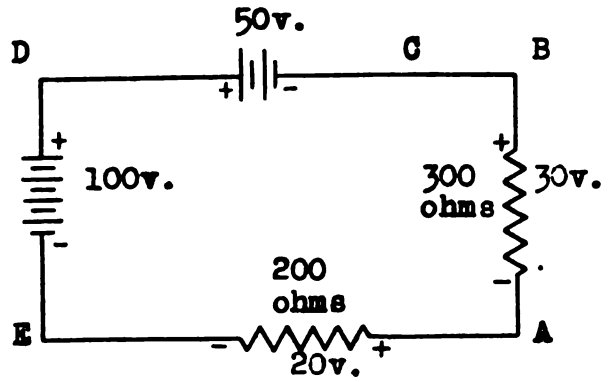

Fig. 3-1: Kirchoff's Second Law.

7. In the circuit shown in Figure 1 the voltage drop across the two resistors must be equal to the voltage applied to them. The net emf (battery voltage) is 50 volts. Therefore there will be 30 volts across the 300 ohm resistor and 20 volts across the 200 ohm resistor.

8. Very often when a voltage is mentioned, the phrase "with respect to ground" is understood. If the negative terminal of the 100 volt battery is considered to be a ground potential (Figure 1, point E), then point A is at plus-20 volts, points B and C are at plus -50 volts and point D is at plus-100 volts--with respect to ground. It would have been as well to have considered point A to be at ground potential. In that case point E would have been a minus-20 volts, points B and C at plus-30 volts and point D at plus-80 volts. Notice that since there is assumed to be no voltage drop in connecting wires, points B and C must be at the same potential.

9. <u>Capacity</u>: Now examine the property of capacity to see how it affects a circuit. Figure 2 consists of a battery and two wires, A and B.

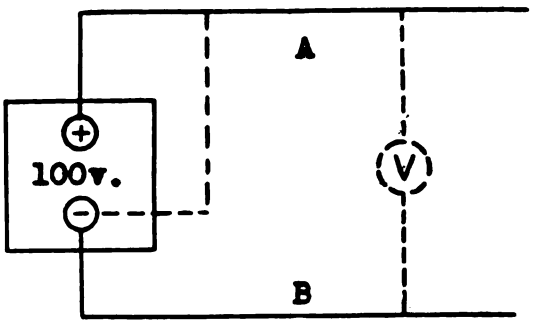

Fig. 3-2: Circuit Capacity.

At the far end of the wires a voltmeter may be connected. Assume that this is a rather unusual voltmeter in that it requires no current for its operation. With both wires connected to the negative terminal there will be zero voltage at the end of the wires, but if wire A is moved to the positive terminal of the battery, the voltmeter will show that there is now a potential difference of 100 volts between the two wires. Something has happened in the open-ended wires to produce this difference of voltage. Electrons have moved from wire A into wire B by way of the battery. If the wires were perfectly shielded from each other, no exchange of electrons would have been necessary to produce the voltage difference; but, since the wires are lying close together and are not shielded, there will be a definite number of electrons exchanged. In fact, the more intimate the relation between the wires becomes, the more electrons wire A will have to give up to wire B by way of the battery in order to stay at plus-100 volts. Remember that there is no actual electrical contact between them. The exact quantity of electrons depends on the electrostatic capacity between the wires. If it is necessary to move one coulomb of a electrons from one side of a

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device to the other to produce a potential difference of one volt, then the device has a capacity of one farad. $Q = CE$ where Q is the charge on either element, C is the capacity, and E is the potential difference between the elements.

10. Any two conductors separated from each other by an insulating material (dielectric) form a condenser. The capacity of condensers used in radio work varies from a few micro-microfarads to about 50 microfarads. The insulating material between the conductors in a condenser is called the dielectric.

11. If the 1 mfd. condenser in Figure 3 is placed across the 100 volt battery, there will be a surge of electrons onto plate B which is tied to the negative terminal of the battery. The electrons piled up on this plate will exert a force, repelling electrons from plate A which move in the direction of the positive terminal of the battery. Thus there is a movement of electrons throughout the circuit and the condenser charges, but it is to be remembered that none of the electrons pass from plate B to plate A through the dielectric.

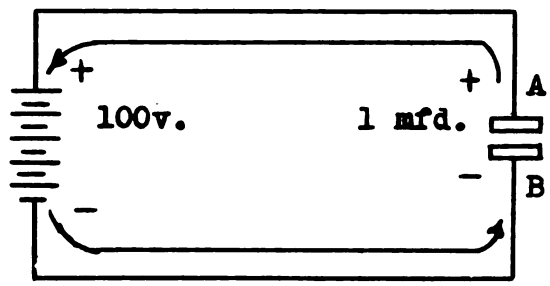

Fig. 3-3: Charging Current in a Condenser.

Whenever the electrons on plate B fail to exert sufficient force to move any more electrons off plate A, the condenser will have the greatest charge possible at the applied battery potential and the circuit will be effectively open. The charged condenser may then be considered as a second battery in the circuit at the same potential as the first and bucking it so that no current will flow in the circuit. The quantity of electrons lost or gained by either plate will equal $Q = CE = 10\text{-}6 \times 10^2 = 10^{-4}$ coulombs (assume no initial charge on the condenser). This demonstrates the most important property of a condenser. <u>Current must flow in the circuit in order to change the voltage across a condenser</u>. The number of electrons which must be exchanged depends directly upon the capacity of the condenser and upon the amount of voltage change.

R.C. TRANSIENTS

12. The manner in which a condenser charges through a resistance when a constant voltage is applied is very important in the study of Radar. The circuit in Figure 4 will be used for the purpose of illustration. With the switch open and no previous charge on the condenser C, there would be no voltage drop across the resistor R. Thus the open-circuit condition of the constants is defined.

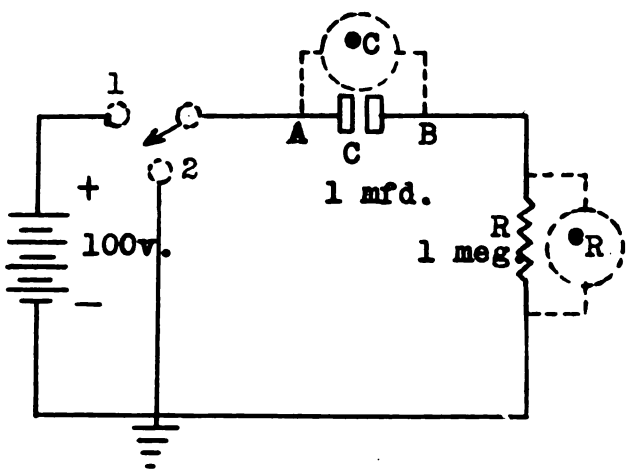

Fig. 3-4: A Simple RC Circuit.

Consider now that the switch is thrown to position 1. It has been

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pointed out in paragraph 11 above that the charge on the condenser builds up as a result of the movement of electrons in the circuit. instantaneously there will be no charge on the condenser and likewise no voltage drop across it. The current at this time, however, is maximum since the initial surge of electrons is greatest. This current flowing through the resistance R produces a maximum IR drop which in this case will equal the applied voltage, since R represents the only resistance in the circuit, and the initial current is determined only by this value (assuming E is fixed at 100 volts). In other words, the potential on both plates of the condenser is plus-100 volts, regardless of the size of the resistor, at the instant the switch is closed.

13. As time progresses, the charge on the condenser increases exponentially from zero, thus rendering the applied voltage less effective in piling up electrons on plate B of the condenser. The current flow in the circuit, meanwhile is decreasing exponentially, and the IR drop across the resistor diminishes accordingly. Thus the interrelationship between the flow of current in the circuit, the charge on the condenser, and the IR drop across the resistor becomes apparent.

14. A study of the properties of an exponential curve is helpful at this time. The curve in Figure 7 might represent any exponential curve--they are all alike--but use it as the curve of condenser voltage in Figure 5, just for the purpose of illustration. In a certain length of time the voltage across the condenser rises to 50% of the battery voltage (the effective voltage in this case). In the next equal interval the condenser voltage again rises by 50% of the effective voltage (but now the effective potential is only 50 volts).

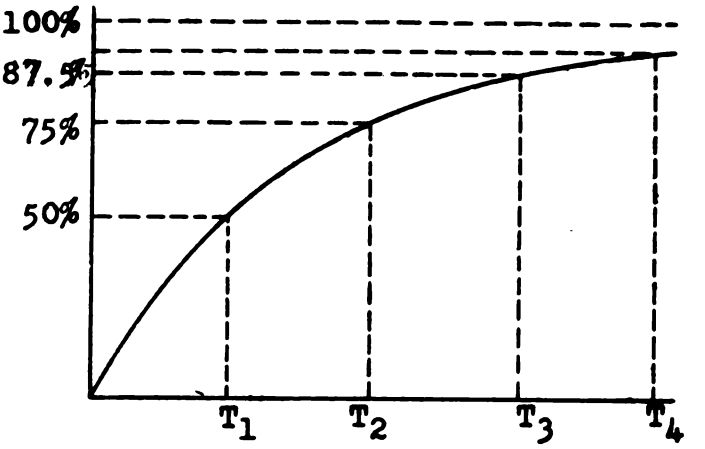

Fig. 3-7: An Exponential Curve.

In the third equal interval the condenser charge increases by 50% of 25 volts, and so on. A little thought will show that the portion of the curve between 50 volts and 100 volts is just as complete an exponential curve as the portion between 0 and 100 volts.

15. Time Constant: After a long time the charge on either plate of the condenser may be expressed as $Q = CE_b$. Now C is a constant (for the case in question, it is 1 mfd.) Therefore, the charge may be considered in terms of voltage as

$$Q: E_b, \text{ C constant.}$$

If e_c represents the charge on the condenser at any instant of time, eventually $e_c = E_b$. However, it will be remembered that at zero time

$$e_c = 0 \text{ volts.}$$

It can be shown that any time "t",

$$e_c = E_b (1 - \epsilon^{-t/RC})$$

Where ϵ is the base of the natural logarithm, (2.718). Considering the circuit constants present which determine the time required to charge the condenser (R in ohms and C in farads)

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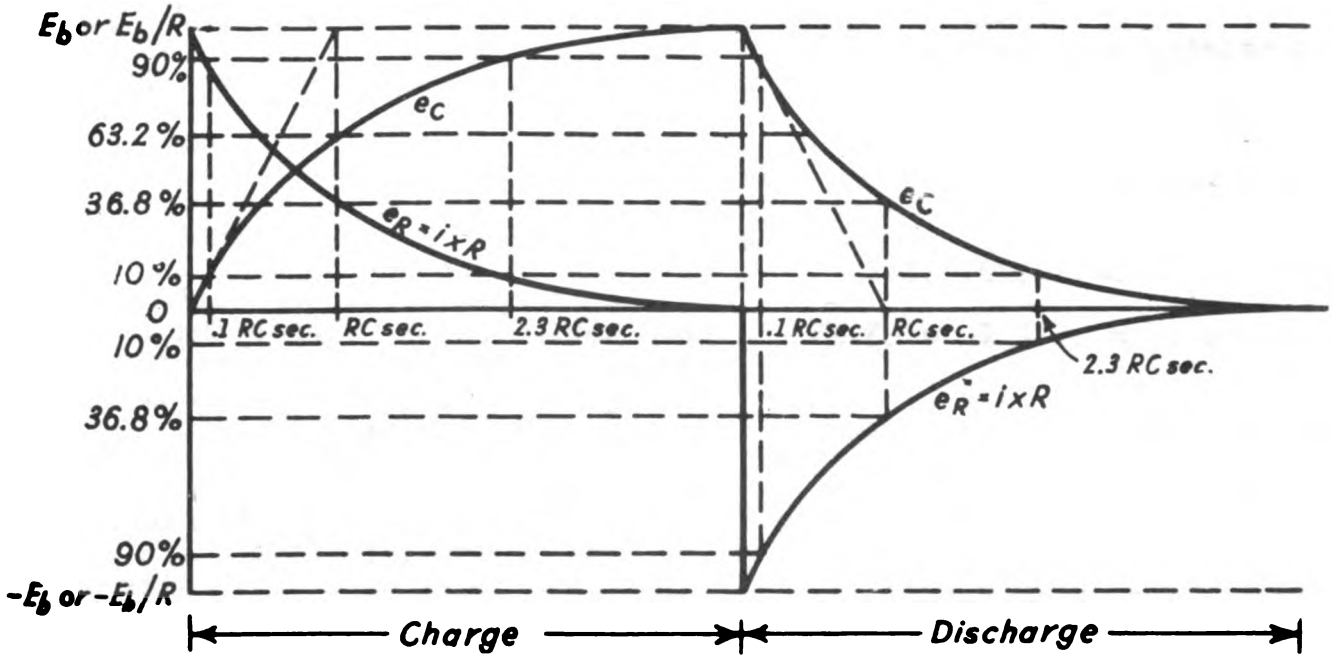

Figure 3-5 Current and Voltage Transients in an RC Circuit

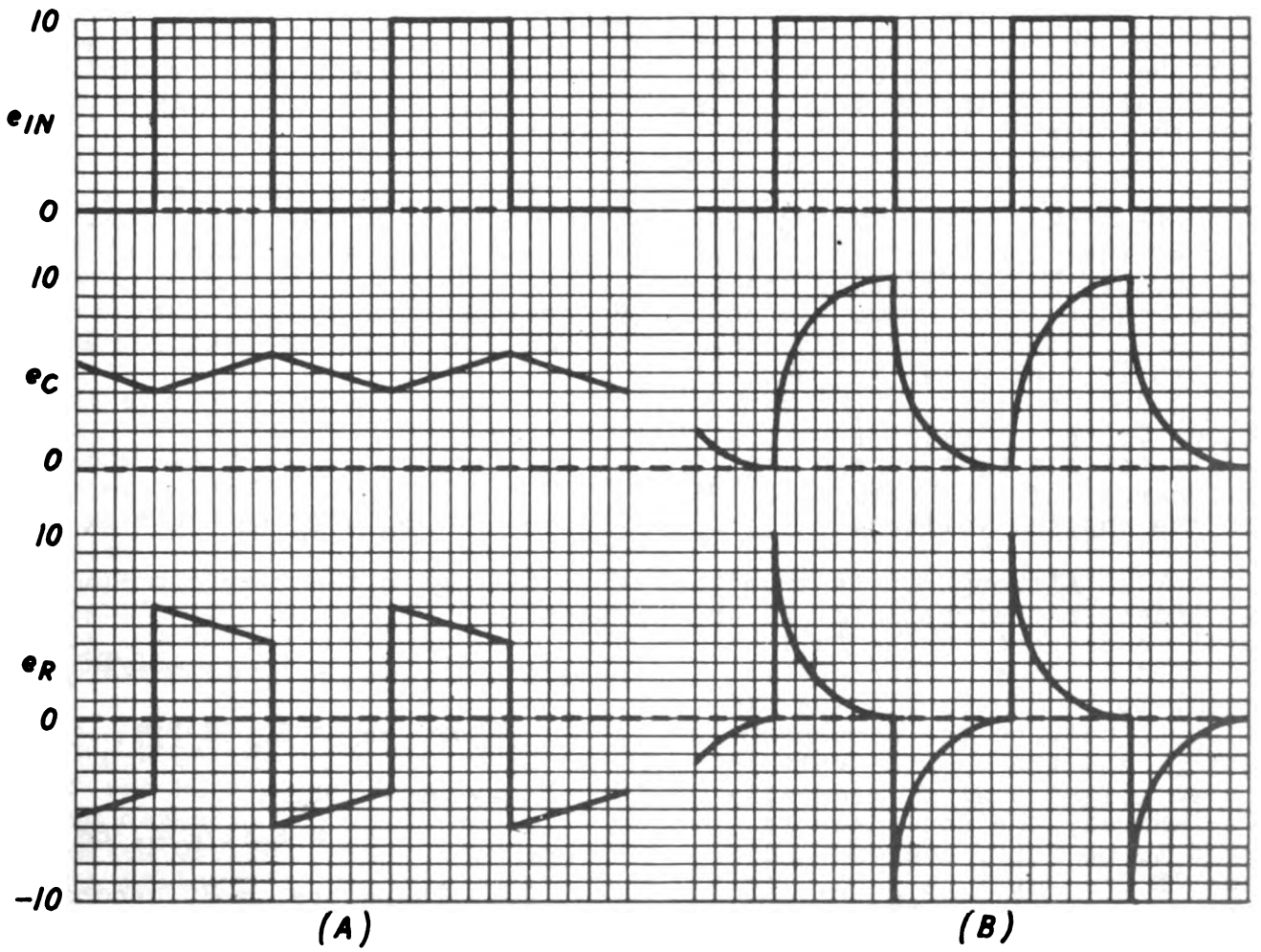

Figure 3-6 Resultant Waveforms of RC Circuits of Different Time Constants

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let $t = R \times C$ seconds.

substituting $e_c = E_b(1 - \varepsilon^{-RC/RC})$

or $e_c = E_b(1 - \varepsilon^{-1})$

now ε^{-1} may be written as $1/\varepsilon$ or $1/2.718$

then $e_c = E_b(1-1/2.718)$

therefore $e_c = .632\ E_b = 63.2\%$ of E_b.

From this development it can be predicted that the charge on the condenser will reach 63.2% of the applied voltage, E_b, in RC seconds. Likewise after RC seconds the IR drop across the resistor will have decreased to 36.8% of E_b. See Figure 5. Since R x C of the circuit in Figure 4 = 10^6 ohms x 10^{-6} farads = 1 second and E_b = 100 volts, then in the time RC seconds the charge on the condenser will have risen from 0 volts to 63.2 volts and the IR drop across the resistor will have fallen from 100 volts to 36.8 volts.

16. The product R x C is called the time constant of the RC circuit and represents the time required to charge the condenser if it continued charging at its initial rate; the current would drop to zero in the same time: Or, practically speaking, it represents the time required to charge the condenser to 63.2% of the applied voltage.

17. Although it is true that a condenser theoretically never will be charged to the full applied voltage, after a time equal to 10 RC seconds the difference between the condenser charge and the applied voltage is so slight that it generally is ignored; the condenser is said to be fully charged and the IR drop will be zero. At the time equal to .1RC seconds the charge on the condenser will be 10% of E_b, or 10 volts, and the drop across R will be 90% of E_b, or 90 volts. At 2.3RC seconds the charge on the condenser will be 90% of E_b, or 90 volts, and the drop across the resistor will be 10% of E_b, or 10 volts. See Figure 5.

18. Now if the switch in Figure 4 is thrown to position 2, the charged condenser will be placed directly across the resistor. Speaking in terms of voltage with respect to ground, at this instant the left hand plate of C is placed at ground potential; since the right hand plate potential is 100 volts below that of the left, the right hand plate is at -100 volts with respect to ground. The charge leaks off the condenser in an exponential manner as would be expected, since the interrelationship between current in the circuit, charge on the condenser, and drop across the resistor is recognized. The action is similar to that which takes place on charge.

19. After a long time

$$e_c = 0 \text{ volts.}$$

However, at the instant the switch was thrown to position 2,

$$e_c = E_b.$$

At any time, t

$$e_c = E_b\ (\varepsilon^{-t/RC}).$$

Consider again the time t = RC seconds.

Substituting, $e_c = E_b\ (\varepsilon^{-RC/RC})$

or $e_c = E_b\ (\varepsilon^{-1})$,

which may be written:

$$e_c = E_b(1/\varepsilon) = .368\ E_b.$$

20. Therefore in RC seconds after the condenser has been placed across the resistor the

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charge on the condenser will be:

e_c = 36.8% of E_b or 36.8 volts,

and this drop will appear across the resistor. Similarly in .1RC seconds the charge on the condenser will be 90% of E_b, and in 2.3RC seconds the charge on the condenser will be 10% of E_b, see Figure 5.

21. The product R x C again is considered to be the time constant of the RC circuit and represents the time required for the charge to reach Zero if it continued at the initial rate; Or practically speaking, it represents the time required to discharge the condenser to 36.8% of its original charge. Thus, on discharge, after RC seconds e_c, e_R, and i will have dropped to 36.8% of their original values.

22. By consulting the waveforms in Figure 6, it can be seen that at any instant the voltage across the resistor added to the voltage across the condenser will be equal to the voltage across the RC combination. This simple fact is an application of Kirchoff's second law, which was discussed in paragraph 6. In this case the algebraic sum of the condenser voltage, e_c, and the voltage across the resistor, e_R, must always equal the input voltage. The waveforms in Figure 6 show the possibilities of developing a useful signal across either the resistor or the condenser. In a later section of this chapter, the uses to which such signals can be put and the means by which they are obtained will be discussed further.

23. Applications of RC Circuits: One of the most important uses of the RC circuit is as a coupling device. For example, it is often desired to pass changes of plate voltage in one tube on to the grid of the next tube without placing the grid at the same operating potential as the preceding plate. The coupling arrangement shown in Figure 8 is used very often for this purpose. With this circuit, variations in plate voltage of V_1 affect the grid of V_2, but such variation takes place about the voltage at the bottom of R (R being isolated from B-plus by condenser C).

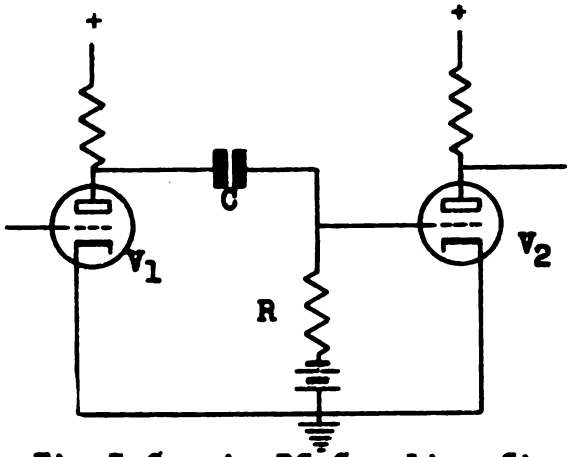

Fig.3-8: An RC Coupling Circuit.

Very often the time constant of RC is so chosen that the waveshape of voltage at the grid of V_2 is the same as at the plate of V_1, while at other times an RC constant is selected which will produce a very definite modification in the waveshape.

24. Long RC: In order to analyze the action of a long RC circuit when variations in voltage are applied to it, the equivalent circuit shown in Figure 9 will be used in conjunction with the waveforms in Figure 10. The generator supplying the input to this RC combination is producing a voltage which varies between plus -50 volts and plus -100 volts with respect to ground.

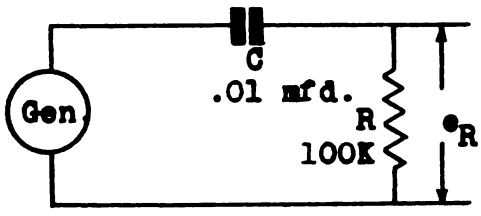

Fig.3-9: The Equivalent Circuit of a Long RC Coupling Network.

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It might be, for example, two batteries with a switching arrangement between them. Notice that the input voltage is held at plus-100 volts for 200 microseconds and then at plus-50 volts for 400 microseconds. Suppose it is desired to pass this voltage variation to the output (e_R) with little change in waveshape. For thispurpose an RC combination which has a time constant that is considerably longer than the time the input voltage is at any one value (400 microseconds) will be used. It is not desired that the condenser change its charge to any great extent during the cycle.

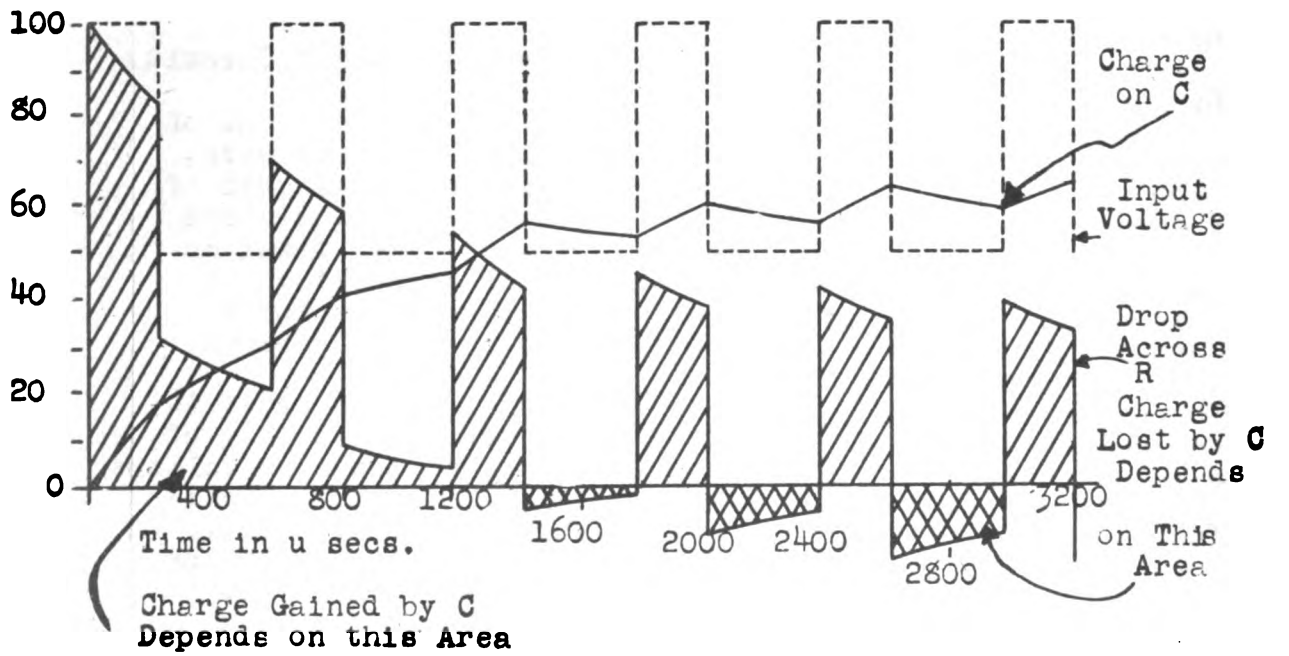

Fig. 3-10: The Charging of a Condenser to an Average Value.

25. <u>The Charging of a Condenser to an Average Voltage:</u> An RC combination which has a time constant that is longer than the period of time of one alternation of the applied voltage is called a long RC. The time constant chosen is $.01 \times 10^{-6} \times 100 \times 10^3 = 1000$ microseconds. It is not an extremely long RC for the waveform frequency under consideration and is used here for convenience.

26. By the use of the complete equation for an exponential curve, it will be found that in this particular case e_R will drop to 82% of its starting value in 200 microseconds and to 67% in 400 microseconds. (In 1000 microseconds it drops to 36.8%) The input voltage is first applied at t = 0 with the condenser discharged. One hundred volts is applied, and, since there is no drop across the condenser at this instant, the full voltage appears across R. Current flow results, and the condenser begins to charge exponentially. These actions may be followed in Figure 10.

27. At the end of 200 microseconds, e_R has dropped to 82 volts (82% of the effective voltage), or in other words, the condenser has charged to 18 volts. At this time the input voltage suddenly drops to 50 volts. There is no reason for the condenser to change its charge

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during this drop, so it remains momentarily at 18 volts. Remember that a quantity of electrons must flow around a circuit to change the charge on a condenser. The 50 volts applied minus the 18 volts in the condenser leaves 32 volts effective across R. During the next 400 microseconds, the effective voltage will drop to 67% of its original value or to plus-21 volts. The condenser charge is 29 volts (50-21). When the input voltage again jumps to 100, there will be 71 volts effective across R(100-29). Once again e_R will drop to 82% of the effective voltage when C charges for 200 microseconds. It drops to 71 x .82 = 58 volts. This action continues exactly in the same fashion and may be followed in the illustration. Notice that C is always charging, so long as the top of R is positive with respect to the bottom; and that, as C charges, the average voltage at the top of R moves downward. The value of the DC voltage at the bottom of the resistor (zero in this example) is very important because of this fact.

28. As soon as the voltage at the top of R begins swinging below this line, current will begin flowing down through R for part of the cycle, decreasing the charge on C. However, the amount of charge gained or lost by C during an alternation depends not only upon the length of time involved, but also upon the amount of effective voltage present. In fact, an exact indication of the charge gained or lost by C during an alternation is given by the area included between the curve and the voltage at the bottom of R.

29. As time progresses, (Figure 10), the condenser will continue to increase its charge every cycle until the average voltage has shifted down far enough that C will discharge each cycle as much as it charges, until the area below the reference line is equal to the area above.

30. Actually, a normally used long RC would have a much longer (relative) time constant than the one shown, and would require longer to reach a stable condition, but assuming it did require 500 cycles to reach equilibrium, this would be only one second after the signal was applied in the case of a 500 cycle-per-second signal. It should be apparent, then, that if the condenser charge does not change appreciable during a cycle, the voltage across R will vary exactly as the input voltage, regardless of the actual waveshape applied.

31. Such an RC combination as shown in Figure 9 can be used as a coupling circuit between stages of an amplifier. This will prevent the DC potential at the plate of the first stage from appearing on the grid of the following stage. As explained in the preceding paragraphs, the voltage variations will, after a short period of time, swing about the potential existing at the end of the resistor away from the grid. Thus the biasing voltage for the tube may be connected to that end of the resistor and the signal will vary above and below that voltage.

32. To summarize the properties of a long RC coupling circuit: First the output voltage (e_R) has very nearly the same waveshape as the input, second, the output voltage has for its direct current component the voltage at the bottom of R, regardless of the DC component of the input, after equilibrium has been reached. Figure 11 shows the wave shape for several types of input. Notice that in all cases the output is swinging about a reference voltage (which is the potential at the bottom

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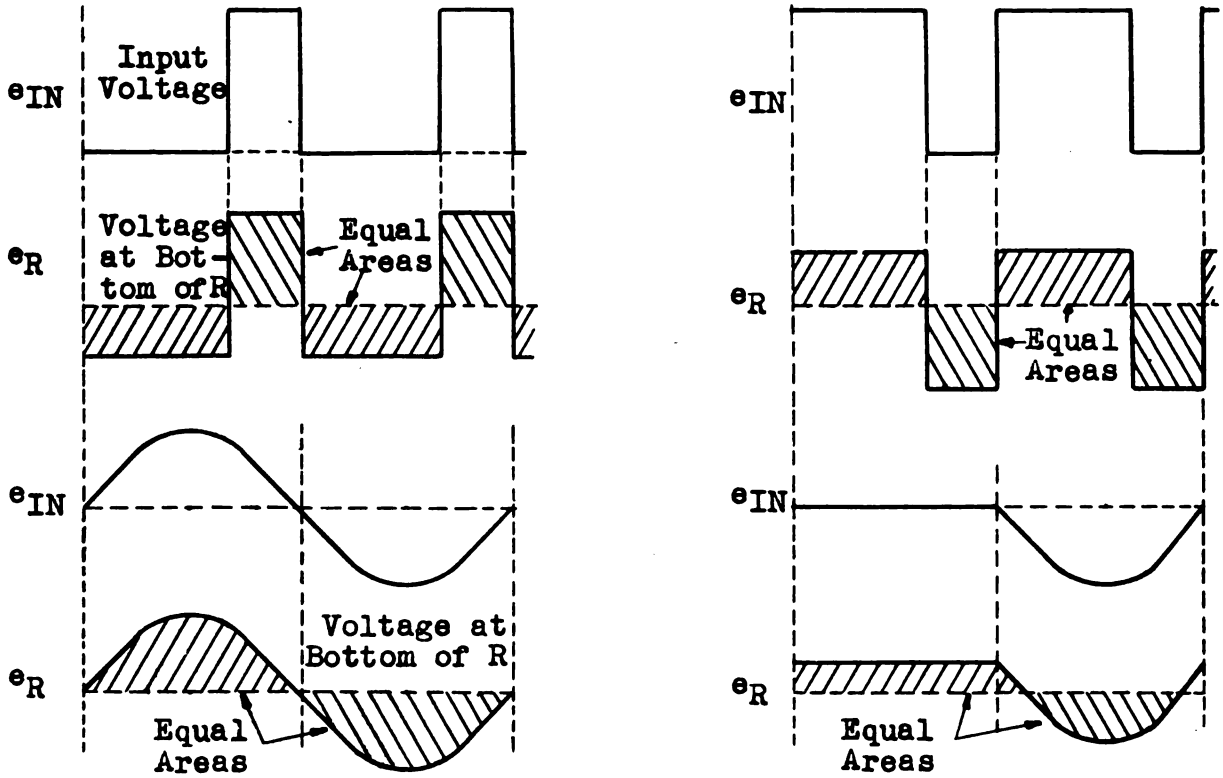

Fig. 3-11: Average Voltages to Which the Condenser of a Long RC Circuit Would Charge for Various Applied Waveforms.

of R) in such a manner that the areas included above and below that line are equal. The voltage across R is now considered to be purely alternating.

33. Short RC: In contrast to the long RC circuit, constants may be chosen which result in an RC combination having a time constant that is shorter than the period of time required for one alternation of the applied voltage. This is called a short RC circuit.

34. Use will be made of the same generator shown in Figure 9 in describing the action of a short RC. A .0001 mfd. condenser will be substituted for the .01 mfd. condenser in the RC circuit (see Figure 12). This change in C produces a time constant of 10 microseconds, and makes the circuit a short RC for the waveform applied. At t=0, the instant the input voltage is applied (no charge on the condenser), the voltage across R will be 100 volts as before.

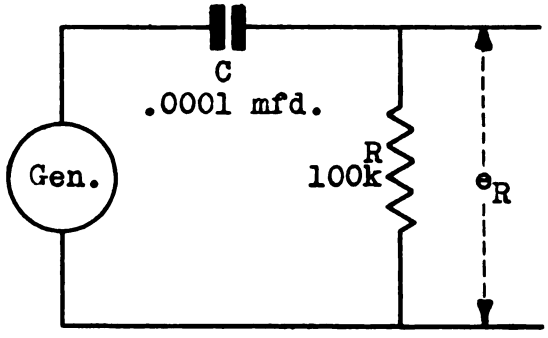

Fig. 3-12: The Equivalent Circuit of a Short RC Network.

This condenser can charge much more quickly, however, at the end of 10 microseconds the voltage across R will be down to 36.8 volts. Long before the end of the first 200 microseconds the condenser may be considered to

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be completely charged to the applied 100 volts and e_R will have fallen to zero. Now when the input voltage falls 50 volts, e_R will likewise drop 50 volts, as in the long RC; but, with 100 volts charge on C, R will go from zero to -50 volts (50 volts applied minus 100 volts in C equals -50 volts at the top of R). C can discharge enough to bring e_R back to 37% of -50 volts in 10 microseconds, thus, long before the end of the 400 microseconds, e_R is at zero and C is charged to plus-50 volts.

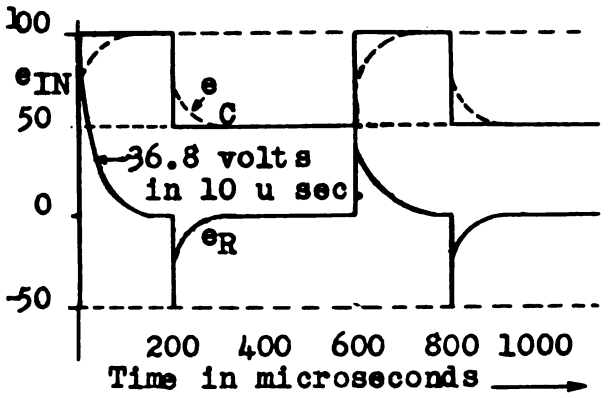

Fig. 3-13: Voltage Waveforms of a Short RC Circuit.

Notice on the graph, Figure 13, that e_C is practically the same as the input voltage waveshape and that e_R is a series of positive and negative pulses, the magnitudes of which are equal to the sudden changes in input voltage. Very often voltages other than a square wave are applied to short RC circuits. It is necessary to develop a means of determining the voltage waveshapes across R when any type of input wave is applied. Probably the simplest approach to the problem is to say that in a short RC the waveform of voltage across the condenser is practically the same as the input voltage. This fact is true because C can charge and discharge so quickly in comparison to the input cycle that the area between e_R and the reference line is very small.

35. RC Differentiator: Figure 14 shows the effect of applying a symmetrical sawtooth input voltage to the RC circuit shown in Figure 12. The applied voltage rises linearly from 50 to 100 volts in 200 microseconds and then falls back again to 50 volts in an equal time.

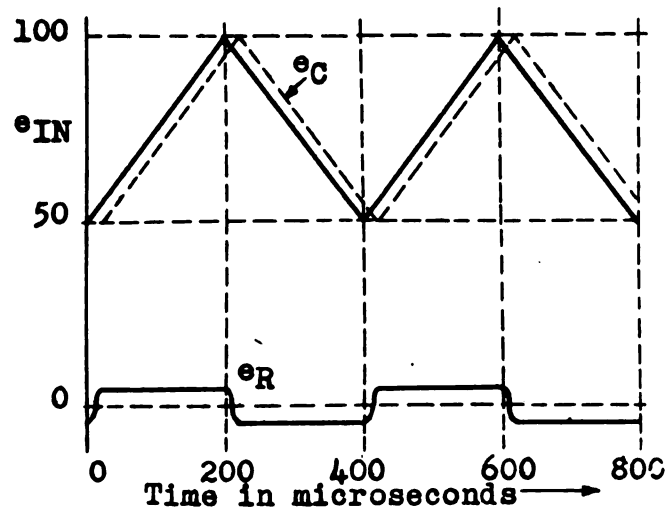

Fig. 3-14: Symmetrical Sawtooth Applied to a Short RC Circuit.

Practically speaking, e_C will rise very quickly to 50 volts and then will charge at a constant rate remaining almost equal to the applied voltage at all times. If, however, the voltage across C is to rise at a constant rate, a constant current must be flowing in the circuit. Remember that if the charge on a condenser is to be changed by the same amount in each unit of time, the same amount of electrons must be moved around the circuit in each unit of time or, in other words, a constant current must flow. This constant current will produce a constant voltage drop across R. Likewise, when the input voltage (and e_C) falls, the condenser is discharging at a constant rate and a constant drop is produced across R in the opposite direction. In a given RC circuit the amount of voltage across R depends not upon the magnitude of the applied voltage, but upon the rate at which

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the applied voltage is changing. Because of this fact a short RC is very often called a "Differentiator" circuit. Differentiation is the name given to a process in calculus whereby the rate of change of some quantity is determined. Simply remember that in a short RC the voltage across R depends upon the rate at which the input voltage is changing.

36. Figure 15 shows several different applied voltages and the e_R which results. Note that in the case of a sine wave the output voltage is also a sine wave but is 90° out of phase with the input.

given rate, the condenser will not instantly start changing its charge at the same rate. In other words, the voltage across R will not immediately jump to its constant value but will build up exponentially to this value.

38. Figure 16 is used to illustrate the factors involved. It is a specific case, but the principle may be applied to any situation. Apply a voltage which starts at zero and rises at the rate of 1 volt per microsecond. The time constant of the RC circuit is 10 microseconds. It is obvious that at the first instant the rate of charge of the condenser is zero, because there

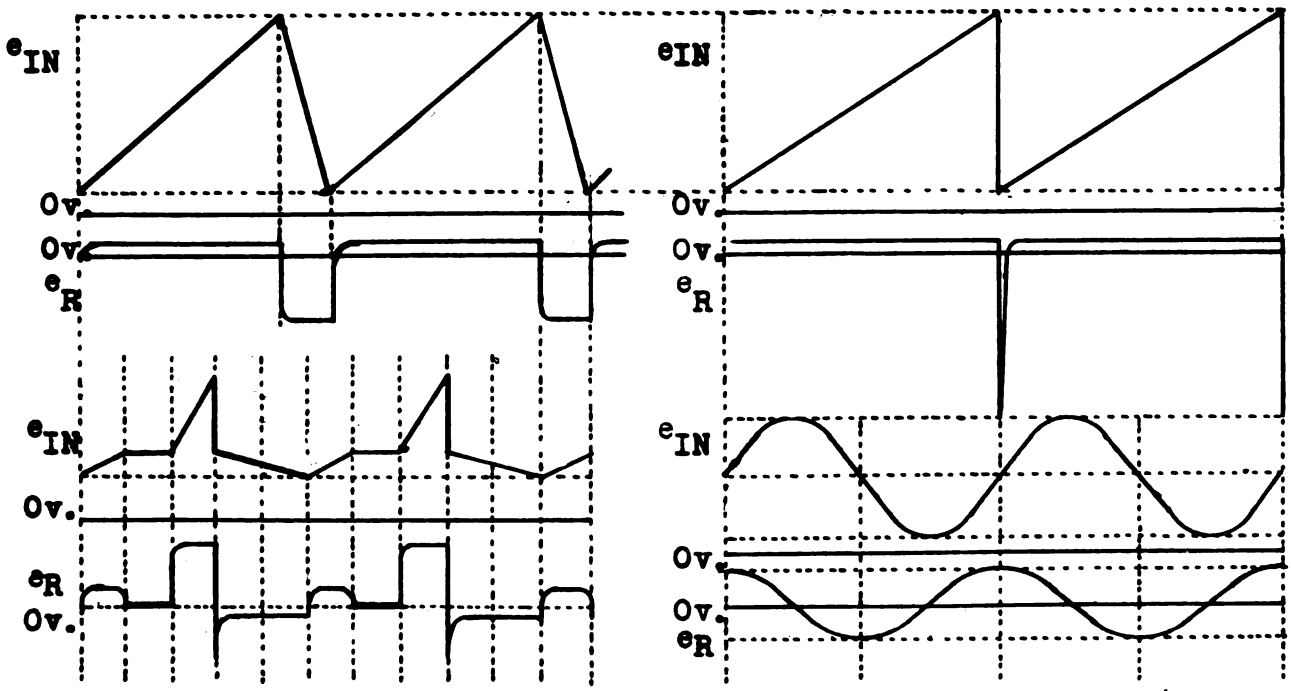

Fig. 3-15: Differentiator Output for Various Input Voltages.

It should be remembered that the magnitude of e_R is usually very small in comparison to the input voltage change.

37. The preceding discussion is a simplified approach to the problem. Actually when the input voltage starts to change at a

is no voltage across R and no current is flowing. Then for a time the condenser will not charge as fast as the input voltage rises. The result is that e_R (the difference between input voltage and e_C) increases. As e_R increases, the charging current increases, and C charges

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faster; but, until C is charging at the rate of 1 volt per microsecond, e_R will continue to rise.

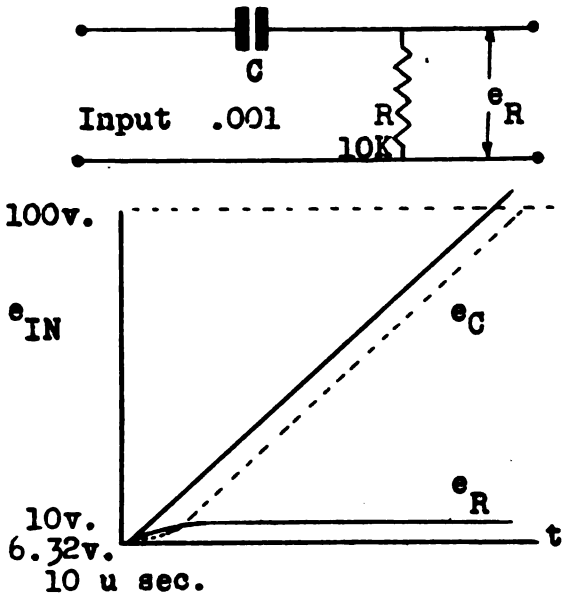

Fig. 3-16: The Initial Charging Rate of a Condenser will not Correspond to the Initial Rise of a Linear Voltage Input.

In order to determine the value of e_R necessary for e_C to rise at this rate, it is necessary to find the current required. C would have to charge to 10 volts in one second; or, in other words, since Q = CE, a quantity of electricity equal to .001 x 10^{-8} x 10^6 = .001 coulombs must flow in the circuit per second. This represents a current of .001 amperes. Ten volts (.001 x 10,000) must be present across R before this amount of current will flow. It may be shown: (1) that the constant voltage across R is equal to K x RC, where K is the rate of change of input voltage in volts per second; and (2) that e_R has reached 63.2% of this value in RC time.

39. RC Integrator: An RC combination is sometimes used as an integrator. Integration is another term taken from calculus. It is a process of summation. Applied to electrical circuits it is a means of obtaining a voltage proportional to the frequency and amplitude of input pulses.

40. There is nothing different about the RC circuit in Figure 17 from those mentioned previously except that the output is taken across C rather than R.

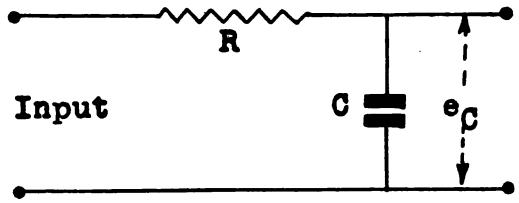

Fig. 3-17: RC Integrator Circuit.

Assume that values are assigned to R and C which result in a long RC time constant for the frequencies of the input waveforms shown in Figure 18. Remember that in a long RC the charge on the condenser (e_C) does not vary appreciably during a cycle, but that over a period of time it will charge so that the voltage across R is purely alternating. In other words, C will charge to the DC component of the input signal, Figure 18.

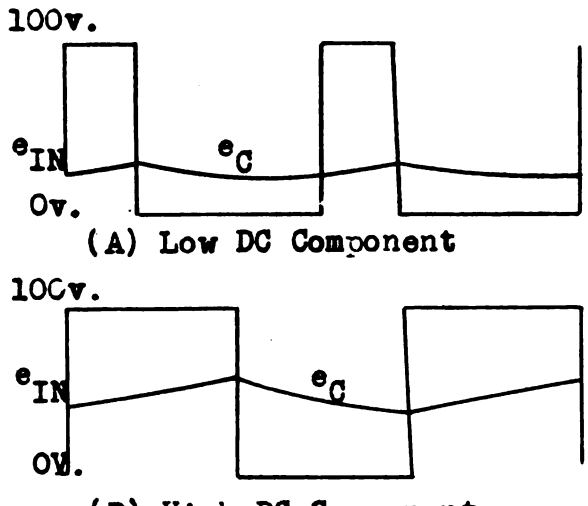

Fig. 3-18: Condenser Charges to the DC component of the input Signal (e_{IN}).

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It is not difficult to see that if the average value of the input voltage is increased, C will charge to a higher voltage. A and B of Figure 18 show the effect of changes in the average input voltage. When the input pulses come along at widely spaced intervals, C will not build up a very great charge; but, when the pulses occur more often, the charge on C will increase.

41. However if values are assigned to R and C which result in a short RC time constant for the frequencies of the input waveforms shown in Figure 18, a somewhat different sort of output voltage will be produced. With a short RC path, the condenser will be expected to charge exponentially to the full value of the input voltage in a period less than the time duration of the applied pulse. This charge will be retained, holding the output voltage (e_C) constant until the applied voltage changes. The condenser will then discharge exponentially to the new value of applied voltage in a period less than the time-duration of this input voltage. The output of the integrator circuit is shown in Figure 19.

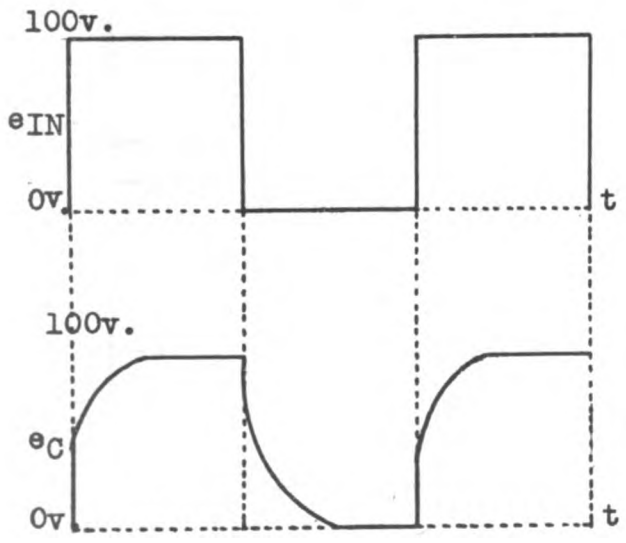

Fig. 3-19: Output of a Short RC Integrator Circuit.

The shorter the RC time constant with respect to the applied frequency the more nearly the output voltage (e_C) will conform to input waveform.

L/R TRANSIENTS

42. Circuits containing inductances and resistance are found very often in Radar. There are many similarities between L/R and RC circuits, but at the same time there are important differences. As with RC, the key to the action of an L/R circuit lies in the properties of the circuit elements themselves.

43. Inductance: Whenever a current flows through a conductor, a magnetic field exists about it, the strength of which varies directly with the current. As the intensity of the magnetic field surrounding a wire is changed, a voltage or pressure is produced in the wire. This voltage is in such a direction that it opposes the change. It tries to prevent the current in the wire from changing. Consider simply a 100 volt battery and a loop of wire connected to the terminal. Before connection is made at the positive terminal of the battery, no current is flowing. At the instant connection is made, the battery will be exerting a force of 100 volts trying to cause electrons to flow around the loop. But current will not instantly jump to its full value. The electrons seem to have considerable inertia; but actually, the fact that a field must exist when current flows is responsible for the action.

44. If no current flows at the first instant, there must be a force in the wire opposing the battery voltage and exactly equal to it. This force is called "counter-emf", and is produced by a magnetic field starting to

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build up about the wire. That property of a circuit which opposes changes in current through it is called inductance. The more inductance a circuit has, the slower the current will rise through it with a given applied voltage. If the current through a device rises at the rate of one ampere per second when a pressure of one volt is applied, it has an inductance of one henry.

45. The inductance of a piece of wire may be greatly increased by winding it into a coil, in which case the field about one portion of the wire also links other portions. Sometimes a magnetic core is used to increase inductance. The voltage across an inductance depends on two factors: The amount of inductance and the rate at which the current changes through the inductance. If the current changes at a constant rate (inductance being a constant value for a particular coil), the voltage level across the inductance must be of constant amplitude. It would be helpful to remember the following comparison between an inductance and condenser: When a constant current flows "through" a condenser, the voltage across it rises at a constant rate; when a constant voltage is applied to an inductance, the current rises through it at a constant rate.

46. All practical circuits have resistance. Consider the action of an L/R circuit (Figure 20) which is similar to the RC circuit of Figure 4, and compare the actions of the two circuits. See Figures 21 and 6.

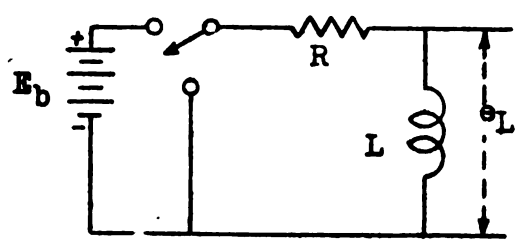

Fig. 3-20: A Simple L/R Circuit.

47. When the switch is thrown to position 1 (Figure 20), two facts are obvious from the characteristics of the components: First, at t = 0, no current will flow; secondly, if no current flows, there will be no drop across R. If e_R is zero, then the full battery voltage must appear across L. Current rises through the circuit at the rate required to produce 100 volts counter-emf in L. As current begins to flow, however, a voltage drop appears across R, and e_L decreases lessening the rate of increase of i. The voltage across R rises exponentially toward the battery voltage and i increases exponentially toward E_b/R.

48. This behavior can best be illustrated by considerations similar to those utilized in the study of RC circuits. After a long time

$$i = E_b/R$$

However, at zero time

$$i = 0$$

It can be shown that at any time, t:

$$i = E_b/R \left(1 - \epsilon^{-Rt/L} \right) ,$$

where $\epsilon = 2.718$ (base of natural logarithm). Considering the circuit constants which determine the characteristics of the circuit, L and R,

let $t = L/R$ seconds

$$\text{substituting } i = \frac{E_b}{R} \left(1 - \epsilon^{-\frac{R\,L/R}{L}} \right)$$

$$\text{or } i = E_b/R \, (1 - \epsilon^{-1})$$

$$\text{then } i = E_b/R(1-1/2.718)$$

$$\text{therefore } i = .632\, E_b/R =$$

63.2% of E_b/R

49. Notice that the curves in Figure 21 look exactly like those in Figure 5. The curves of e_L

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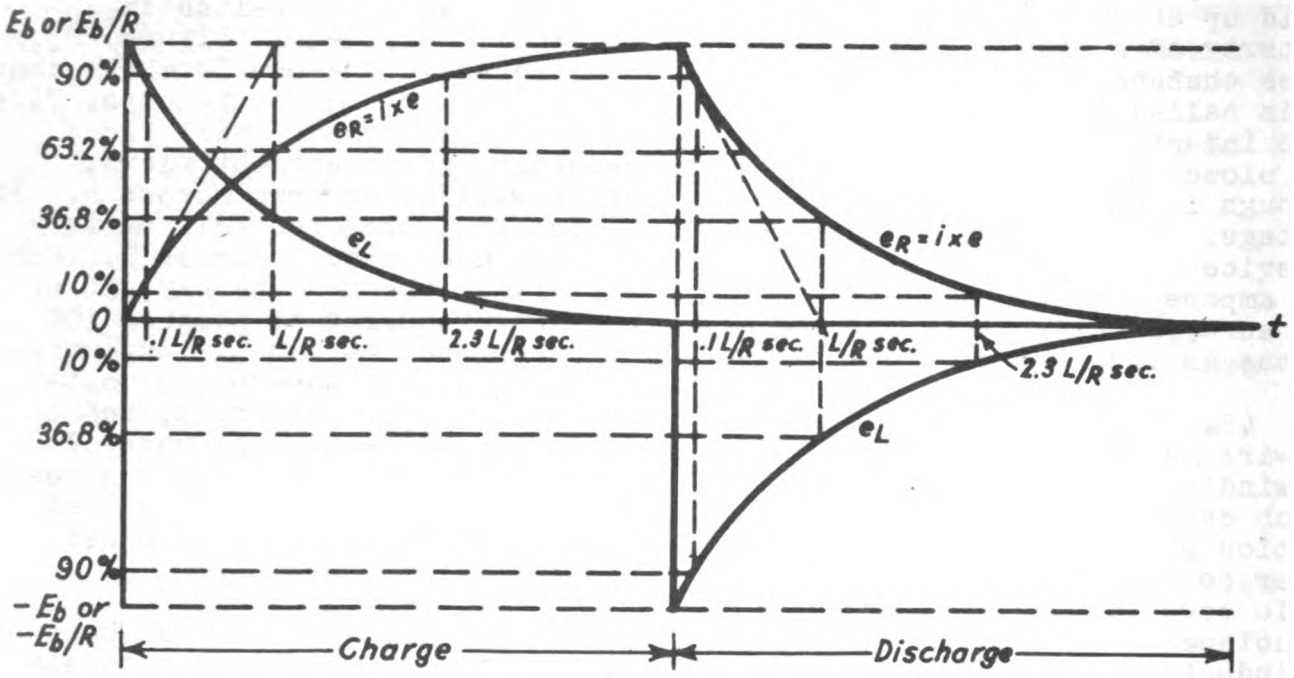

Figure 3-21 Current and Voltage Transients in an L/R Circuit

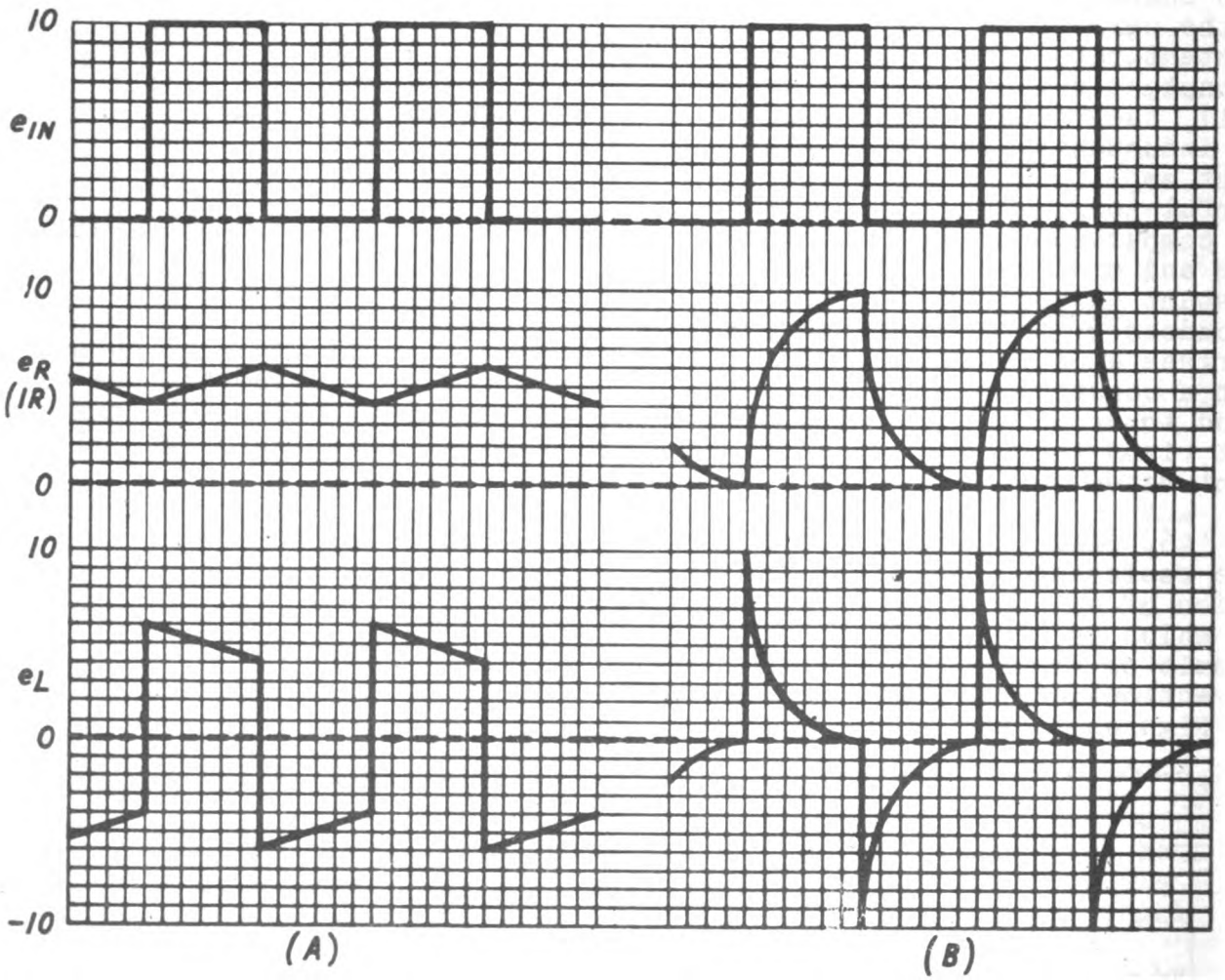

Figure 3-22 Resultant Waveforms of L/R Circuits of Different Time Constants

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and e_R correspond respectively to e_R and e_C. The time constant in the case of an inductive circuit is L/R; e_R will be at 63.2% of E_b and e_L will have fallen to 36.8% of E_b. The time constant of the circuit shown is L/R = 1/1000 = .1 ampere. Increasing L increases the time constant because it will take longer for i to rise to .1 ampere. Increasing R, however, will decrease the time constant because, although i starts increasing at the same rate, it does not build up to as high a value.

50. If, after approximately 10 x L/R seconds the switch is thrown to position 2, the following results will be apparent. Because of L, the .1 ampere that has been flowing will not suddenly change. The counter-voltage of L will prevent any instantaneous change in current. If it is to remain momentarily the same, e_R must remain momentarily at 100 volts; since the left side of R is at ground potential, its right side must be at -100 volts. In other words, the counter-voltage produced in L to keep the current flowing is 100 volts, of polarity opposite to that existing when the switch was in position 1. This counter-voltage is being generated by a falling current--falling at the same rate at which it was built up, because the same voltage is produced. e_L, i, and e_R all fall exponentially toward zero. This can be shown by application of the expression for the decay of current in the L/R circuit:

$$i = E_b/R\ (\epsilon^{-Rt/L})$$

by substituting t = L/R, it is seen that

$$i = 36.8\% \text{ of } E_b/R$$

in L/R seconds after the switch is thrown into position 2.

51. L/R Coupling: An L/R combination is sometimes used for coupling between circuits. The L/R network acts exactly the same as an RC combination of like time constants, as far as voltage waveforms are concerned. There is this difference, however: The average current in an L/R circuit depends upon the DC component of the input signal and is generally not zero. Since R is taking the place of C, the DC component of the input signal must be dropped across R by current flow through it. See Figure 22 for a comparison of the two circuits.

52. In an RC circuit, tne average charge on the condenser changes from one cycle to the next until it is charging and discharging an equal amount. In an L/R circuit the current keeps changing from one cycle to the next until it has reached a value where it is increasing and decreasing the same amount. The area under the curve of e_L determines how much change in current takes place during an alternation.

53. Inductive coupling is used wherever it is desirable to have the plate voltage of a vacuum tube vary about (above and below) the supply voltage rather than about some lesser value as in resistance coupling. The essential circuit is shown in Figure 23. With the inductance forming a long L/R with the plate resistance of the tube, the output will be the same as the signal voltage at the grid so long as the grid remains within the linear region. An RC coupling is still usually necessary to couple the output to its load.

54. L/R Differentiators: In a circuit containing resistance and inductance, such as shown in Figure 23 (B), if suddenly a voltage is applied across the combination, at the first instant all of the voltage will appear across

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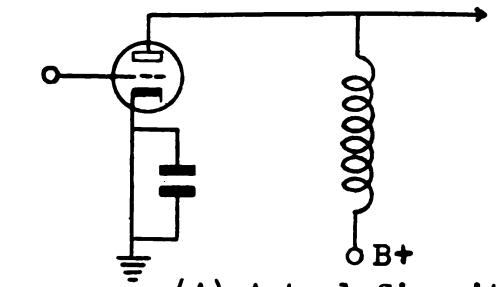
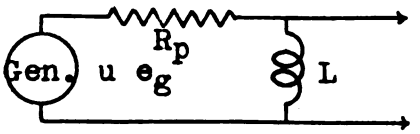
the inductance, since no current is flowing in the circuit. By reference to the curves in Figure 21 this is found to be true.



(A) Actual Circuit



(B) Equivalent Circuit

Fig. 3-23: Inductive Coupling

Then as current starts flowing, the voltage across L will decrease exponentially. If the time constant of the L/R circuit is short as compared to the period between cycles of square waves applied, the output will be far different from the input. The output voltage taken across L will be sharp pulses, the width of which will be determined by the L/R constant.

55. Assume that square waves of voltage are applied to the L/R circuit shown in Figure 25.

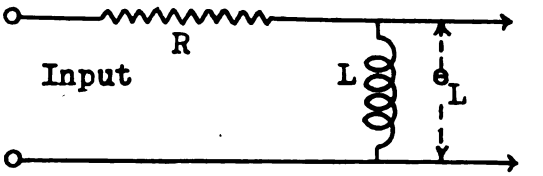
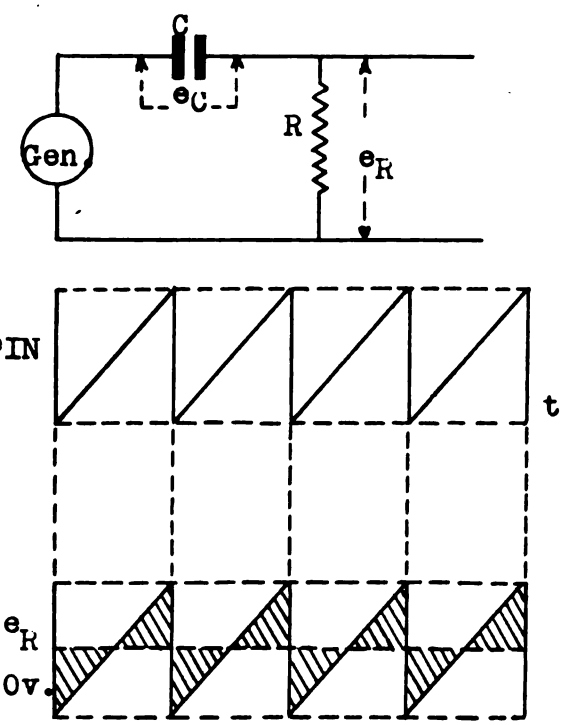
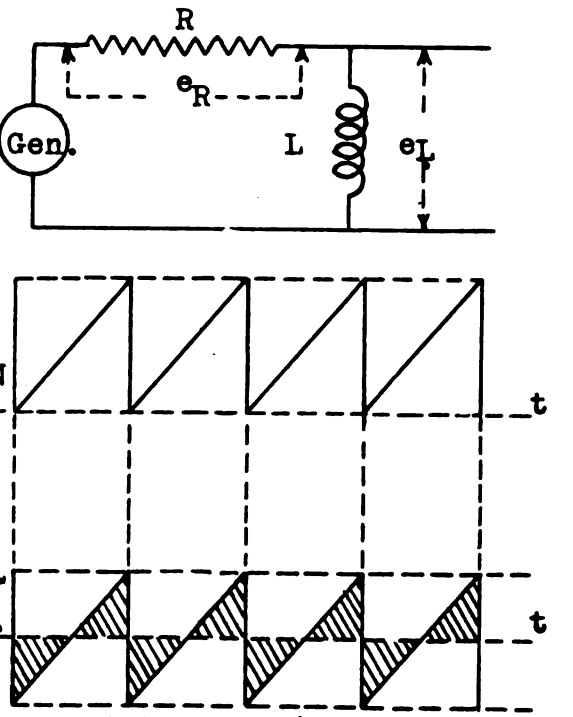


Fig. 3-25: An L/R Differentiator.

Such a waveform is shown in Figure 22(B) as e_{in}. As each change in voltage is applied to the circuit, the same change appears at its output. But since the time constant is short the current will rise rapidly, reaching the value E_b/R in a time less than the time-duration of the applied pulse (Figure 25(B)). As the current rises exponenti-



(A) Long RC Circuit



(B) Long L/R Circuit

Fig. 3-24: Comparison of RC and L/R Coupling Circuit.

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ally, the IR drop increases similiarly and the output voltage will decay at the same rate. This is shown in the waveform of Figure 22(B) as e_L. These sharp pulses may be applied to various circuits just as the output of an RC differentiator is employed.

56. L/R Integrator: In the same manner in which the differentiated voltage waves were taken across the inductance in a circuit containing resistance and inductance, integrated voltage waves may be taken across the resistance. In Figure 26, an L/R integrating circuit is shown, the output being taken across the resistance. As in a differentiating circuit, the L/R circuit merely forms a voltage divider network, from which can be taken voltages which vary as the current through the combination varies.

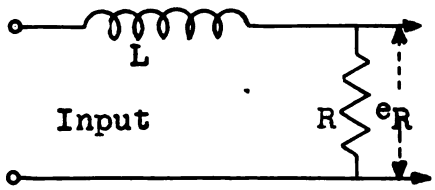

Fig. 3-26: An L/R Integrator

At the first instant in the differentiating circuit all of the voltage appears across the inductance; in the integrating circuit the same action occurs. The voltage to be used, however, (E_R), will be zero at this time. An instant later the voltage across the inductance will begin to decrease and the voltage across the resistance will begin to rise. This action is shown in Figure 22. Assume that square waves of voltage are applied to the circuit shown in Figure 26. In Figure 22(A) such a waveform is shown as e_{in}. As explained above, at the first instant, the output will be zero volts since there is no current and no IR drop present across R. But the voltage across R starts to rise with the flow of current through the circuit, in the manner shown in Figure 22(A) as E_R. Now as the end of the square wave is reached, another rapid change in voltage is encountered and the voltage starts to decrease across the resistance as the current through the circuit starts to fall at the same rate as the original rise. If the L/R constant is long, the output will be a sawtooth of voltage; if it is short, the voltage will be an exponential waveform as shown in Figure 22(B) as e_R.

TRANSIENT ACTION IN RADAR

57. In ordinary applications transient action may be ignored almost entirely due to the fact that the time considerations are of such magnitude as to render the action insignificant. Transient disturbances occur in electrical circuits whenever any circuit condition changes, i.e., opening and closing of switches, etc.

58. In Radar applications, however, the technique of measuring extremely short intervals of time is being developed to a remarkable degree. Under these circumstances transient considerations are of paramount importance. Not only is transient action a factor to be dealt with in Radar technique but it serves as the very basis for the development of this technique. Thus it may be said safely that RC and L/R transients hold the most prominent position among the fundamental principles underlying Radar Performance.

59. The student technician will find it extremely beneficial to devote the time necessary to develop an adequate understanding of the performance of RC and L/R circuits.

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This may be accomplished by: (a) thorough familiarization with the current and voltage transients of circuits containing resistance and capacitance or inductance; i.e., recognizing that time is required for the charge (across a condenser) or for the current (through an inductance) to change its level; (b) considering the R, L, or C of a circuit as elements of a voltage-divider network, and applying Kirchoff's law.

60. These few steps, it would seem, represent the simplest approach to the type of analysis essential to an adequate understanding of a large portion of the circuits comprising any type of Radar equipment.

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CHAPTER IV

Cathode Followers

1. The cathode follower is a degenerative vacuum tube circuit in which degeneration is produced by an unbypassed cathode resistor, the output being taken across this resistor. This circuit is essentially an impedance matching device with less than unity voltage gain but possessing power gain. Its high input impedance and very low output impedance render it particularly suitable for coupling between pulse generating or pulse transmitting stages and transmission lines or circuits whose shunt capacity might otherwise cause objectionable effects. The cathode output voltage "follows" the grid input voltage, hence is of the same polarity.

2. Uses: In Radar it is often necessary to feed the output of one unit through a coaxial cable. This coaxial cable will be, in some cases, as long as fifty feet. There is a certain amount of capacity between the inner and outer conductors that represents an impedance to the signal to be transmitted through the cable. In other words, this capacitance has to be charged each time a pulse is sent through. If too much of the signal is wasted in charging the capacity of the line, there will not be enough useful voltage appearing at the other end of the line to accomplish the action desired in that circuit.

3. It is desirable, of course, to transmit the signal through the coaxial cable with as little loss as possible and with a minimum amount of distortion. The output impedance of an ordinary amplifier is usually very high and if this amplifier works into a low impedance load (such as a coaxial cable) only a small amount of the original signal would appear at the far end of the line as useful voltage. For these reasons a low impedance output stage is desired.

4. Operation: The cathode follower amplifier, shown in Figure 1, is a single stage inverse feedback amplifier in which the output voltage is taken across the cathode resistor. Notice the absence of a cathode bypass condenser. Also notice that there is no plate load resistor and that the output of the circuit is taken across the cathode resistor.

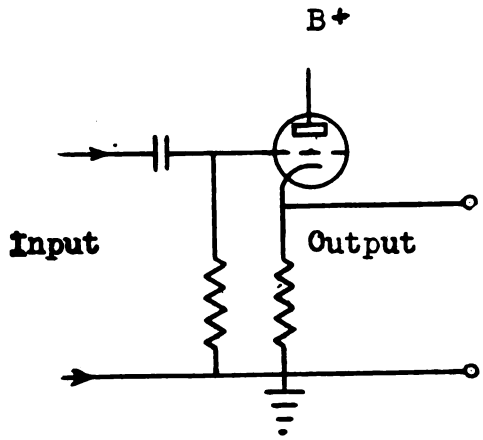

Fig. 4-1: A Conventional Cathode Follower.

5. Consider the circuit with no signal applied to the grid. There will be a certain amount of current flowing through the tube. The product of this current and the resistance in the cathode circuit will give the amount of no-signal bias developed across that resistance. If the grid is driven in a positive

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direction, the tube current will increase and the IR drop across the resistor will increase. The bias will be varied with the signal amplitude, reducing the effect of the input signal as the cathode tends to "follow" the variations in grid potential. If a sine wave is applied to the grid, a sine wave of less amplitude will appear across the cathode resistor. The circuit is then a negative feedback or degenerative amplifier. Without entering into the mathematical derivation, the gain of the stage can be calculated from the following equation:

$$\text{Gain} = \frac{uR_k}{R_p + R_k\ (1+u)}$$

Where
u = Amplification factor of tube
R_k = Resistance of cathode resistor
R_p = Plate resistance of tube

The presence of the quantity (1+ u) in the denominator of the equation assures that the gain of the cathode follower will always be less than unity. The circuit is a de-amplifier. However, considering the advantages of the stage, the loss in gain is not objectionable.

6. It is important to note that the output waveform will be "in phase" with the input waveform. That is, it will be of the same polarity. Remember that as the grid was going positive the cathode was also going positive. Likewise, as the grid was going negative, the potential of the cathode was going in a negative direction. This differs from the ordinary amplifier in that the output voltage is normally inverted or reversed in polarity.

7. As long as the grid is not driven positive with respect to the cathode, then the input impedance of the cathode follower is high. This circuit will not, therefore, "load" the previous stage. On the other hand, the output impedance is comparatively low. This impedance can be calculated by dividing the plate resistance of the tube by its amplification factor and will be of the order of 750 ohms. This output impedance can be as low as 170 ohms.

8. It has been mentioned that one application of the cathode follower is to use it to feed a pulse into a coaxial line. Another practical advantage of the device is that it may be coupled to the following stage without the use of a coupling condenser, so that the DC voltage as well as the AC components of the signal will be transmitted. The DC voltage must not, however, be great enough to overcome the bias set up by the cathode resistor of the second stage.

9. When it is desired to obtain a low output impedance with a large voltage output, it is possible to employ several tubes in parallel in one stage. The loading effect of such a combination of tubes is not materially worse than that of a single stage, since the capacitance values of the combination are equal to the sum of the capacitance values of the individual tubes.

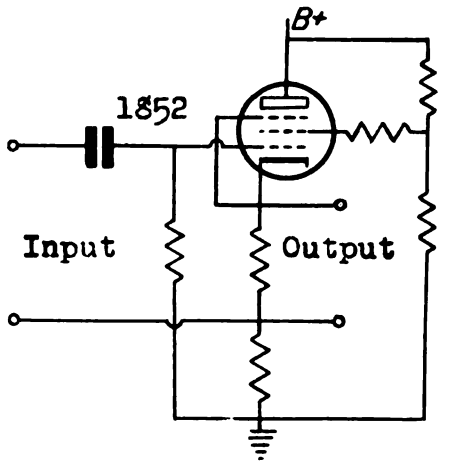

Fig: 4-2: A Cathode Follower Employing an 1852 Pentode.

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10. The cathode follower may also be used in conjunction with the oscilloscope. This application is used when the input impedance of the oscilloscope is so low that it causes the waveforms being observed to appear distorted. Such an effect will be present, for instance, if an oscilloscope with an input impedance of about 5 megohms is connected across a grid circuit with an impedance of 10 or 15 megohms. This parallel impedance will cause a marked effect on the signal since the time constant of the circuit has been reduced considerably. However, if a cathode follower is connected between the high impedance circuit under consideration and the oscilloscope the impedance of the circuit will not be altered appreciably. Therefore, the waveform on the oscilloscope will be a true representation of the action in the circuit, i.e., free of distortion.

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CHAPTER V

Blocking Oscillators

1. A Blocking Oscillator is any oscillator, running freely or controlled by a synchronizing voltage, which cuts itself off after one or more cycles by the flow of grid current charging a grid capacitor. Airborne Radar is concerned with two general types of blocking oscillators; the self-pulsing RF oscillator, and the single cycle or single swing timing oscillator. The former serves as the transmitter in some Radar equipments; the latter may be used to determine the pulse recurrence frequency of a Radar transmitter. When so used, it is often referred to as a Repetition Rate Oscillator, Timing Oscillator, or Base Oscillator.

2. Before considering the theory of operation of the blocking oscillator, it would be well to review the theory of ranging by means of radio waves and see why a pulsing type of RF oscillator is used in the Radar transmitter.

3. In determining the distance to the target it will be remembered that a pulse of radio frequency energy of short time duration is transmitted and then a comparatively long period of time is allowed for this pulse to reach the target, be reflected, and return to its point of origin. During the time the pulse is going out to the target and returning to its place of origin, the transmitter must be off the air or resting. Obviously, if the transmitter were allowed to transmit continuously there would be no practical way of measuring the time required for each oscillation to travel out to the target and return. Thus it becomes necessary that the transmitter operate for a short period of time and then remain off the air for a comparatively long period of time. During this inoperative period the pulse goes out to the target, is reflected, and returns to its point of origin. Meanwhile the indicator measures the travel-time of the pulse and provides a means of establishing the range of the target in miles or yards.

4. It is evident that each pulse of radio frequency energy should be as powerful as possible. This requirement can be approached in two ways. The first method is to use as much power as possible. However, in aircraft equipment space and weight place a limit on this factor. The second method is to design the equipment so that each oscillation within the pulse has maximum amplitude. Since the transmitter is working for a short period of time and then resting for a long period of time, it may be greatly overloaded for the short transmitting period and allowed to cool off during the long resting time. This makes it possible to design a transmitter with a very high pulse power for its size and space. When the transmitter is designed for heavy overloading on each pulse, it must not be allowed to break into continuous wave operation (CW) otherwise the tubes will remain over heated and will be damaged.

5. In examining the operation of the blocking, or self-pulsing RF oscillator, the Hartley type will be referred to because of its simplicity, although

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the blocking principle may be applied to almost any of the conventional types of oscillators. The circuit of the Hartley Oscillator is shown in Figure 1(A).

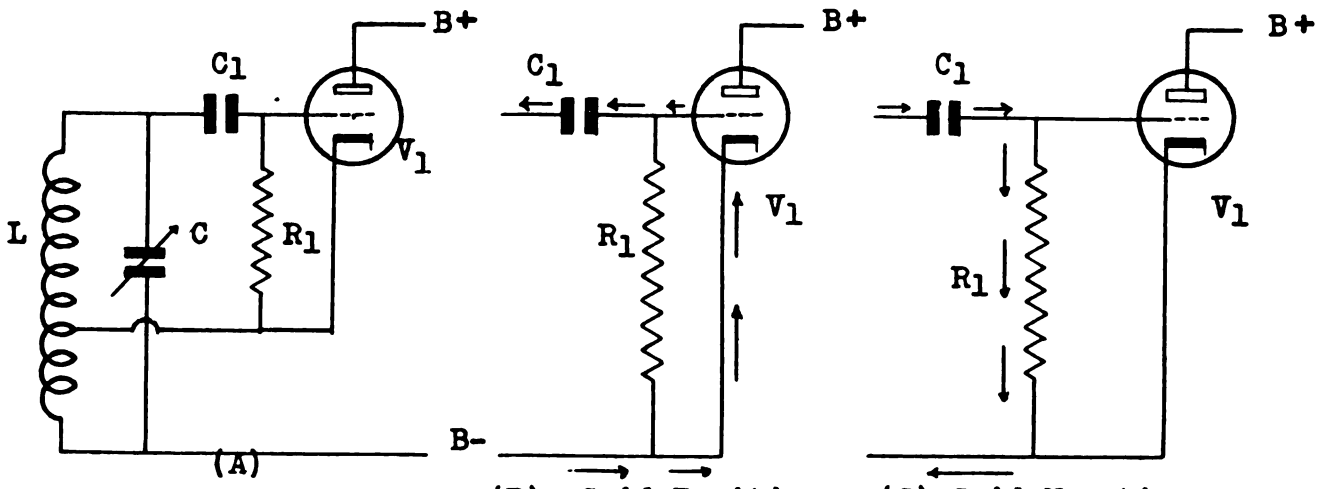

Fig. 5-1: The Hartley Oscillator

In this oscillator the Radio frequency of oscillation is determined by the LC constants of the tank circuit. The theory of operation may be reviewed in any text on radio theory and only that portion necessary in the consideration of pulsing action will be presented here.

6. CW Operation: With this circuit oscillating, the grid of V_1 will be driven alternatively positive and negative. When the grid is positive with respect to its cathode, there will be a flow of electrons within the tube from cathode to grid. See Figure 1 (B). Because the electrons can flow only to the grid side of the grid condenser C_1 and not through its dielectric, they will pile up on this plate. The condenser will therefore take on a charge such that the grid side is negative with respect to the tank side. When the grid of V_1 is driven negative on the next half of the RF cycle, there can be no flow of electrons thru the tube and the only path for the flow of electrons will now be through the grid leak R_1. See Figure 1 (C). This means that some of the previously trapped electrons will leak off through the grid leak R_1 and the grid condenser will lose part of its charge during the negative portion of the cycle.

7. The charging up of the grid condenser through the low grid-to-cathode resistance of the tube, and the discharging of this condenser through the comparatively high resistance of the grid leak builds up an average DC voltage on the grid condenser which is called the grid bias. The polarity of this bias is such that the grid will be negative with respect to its cathode. This method of obtaining bias is called the condenser-grid leak method. It has several advantages over other methods of bias, namely: (a) It uses but a few parts and is therefore relatively simple. (b) It assures quick starting of the oscillator. When the circuit is first started off, the grid condenser will be in a discharged state and therefore V_1 will have no grid bias. Under these conditions the tube will be very sensitive and a very minute disturbance in the grid circuit will be amplified greatly, starting oscillation. (c) Automatic

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oscillation Amplitude Regulation: If the circuit should tend to oscillate more vigorously, it would drive the grid of V_1 more positive, therefore building up a larger negative voltage or bias on the grid condenser. This will reduce the amplification factor of the tube, thus tending to reduce the amplitude of the next RF oscillation. If the amplitude of the oscillation should tend to decrease, the grid bias will drop as a result of the grid of V_1 being driven less positive. This in turn will raise the amplification factor of the tube and tend to make the next oscillation stronger. Under these conditions the circuit will oscillate continuously and is called a continuous wave or CW transmitter.

BLOCKING ACTION

8. If the grid leak R_1 is increased in value, a point will be reached wherein this regulating action can not keep the amplitude of the oscillations within reasonable limits. The RC circuit now formed by the grid leak and grid condenser will have such a long period that C_1 can not discharge sufficiently before the next cycle comes along. As a result of this condition each successive cycle will add additional charge to the grid condenser until a point is reached where this voltage will be so high that the amount of feedback provided is not sufficient for oscillation to continue. The circuit will not break into oscillation again until the charge appearing on C_1 is low enough to allow V_1 to conduct and therefore permit oscillation to recommence. This results in periods of oscillation followed by periods of rest, a condition which was termed "motor-boating" (for a number of years). It was an undesirable condition because the audible sound produced by a low pulse frequency sounded similar to a motor boat.

9. This heretofore undesirable condition now finds application in the RADAR transmitter. As a result the transmitter oscillates for a short period of time and then rests for a comparatively long period of time. During the time that the transmitter is working or on the air, the average grid voltage is building up to a point where it will stop all oscillations and put the transmitter off the air. When the transmitter goes off the air, the charge on the grid condenser C_1 slowly leaks off through the grid leak R_1, until the negative grid voltage drops to a point low enough to cause V_1 to conduct, thus starting oscillation. This action is shown in Figure 2.

10. In Figure 2 it will be observed that the circuit starts off from the point where the grid condenser C_1 is completely discharged. This means that the grid bias starts out at zero. During the initial pulse the grid bias increases until it reaches the point where oscillation stops. From then on and for each succeeding pulse the grid bias will only vary between the "oscillations stop" level and "oscillations start" level. Actually the grid bias will overshoot the "oscillations stop" value due to the flywheel effect of the LC circuit, which will tend to keep oscillating after the tube has been blocked or cut off.

11. This type of oscillator is often said to oscillate at two frequencies which are; (a) the fundamental radio frequency, and (b) the pulsing frequency. The fundamental frequency is determined by the LC constants of the tank circuit and the pulsing frequency is determined by the RC constants of the grid circuit. The rate at which these

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pulses occur is measured in number per second and called the pulse recurrence frequency or PRF.

12. Figure 2 shows the average grid voltage appearing at the grid of V_1.

where oscillations will be stopped, the grid of V_1 will have to go positive five times during the pulse width. This is shown in Figure 3. It will be observed that the grid of the oscillator tube goes positive with respect to its cathode five times and during

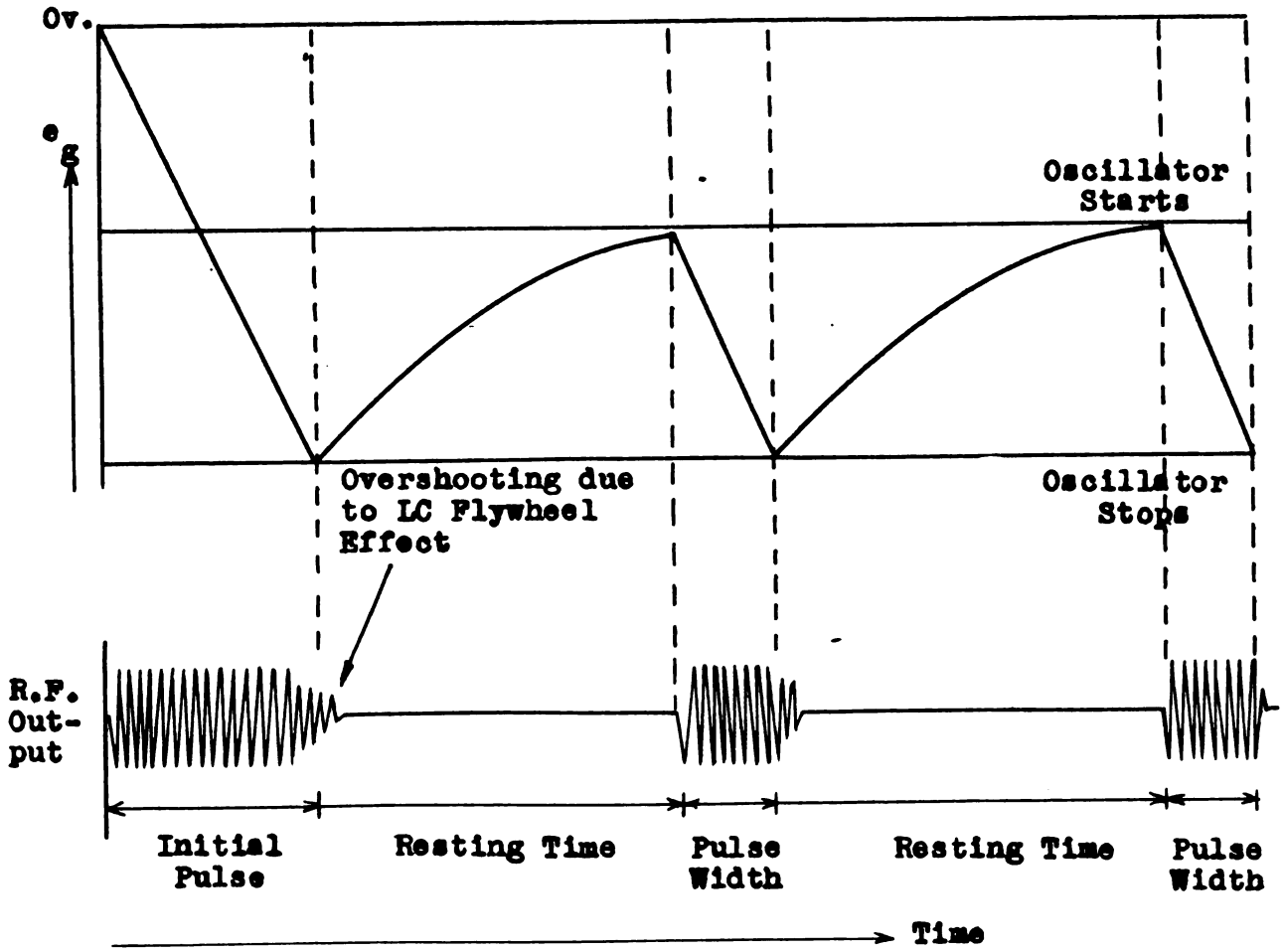

Fig. 5-2: Blocking Action Produces Intermittant Pulses of RF Energy.

The actual grid voltage at any instant of time will look quite a bit different from this. It will be remembered that the grid of the oscillator tube must go positive on every positive going portion of the RF cycle thus charging the grid condenser. This means that if it takes five RF cycles to build up the grid voltage to a point

each of these swings C_1 takes on more charge, because the grid leak does not completely drain off this charge on the negative part of the cycle. As shown in the lower portion of Figure 3, the charge on C_1 progressively builds up until a point is reached where it is high enough to stop the oscillations.

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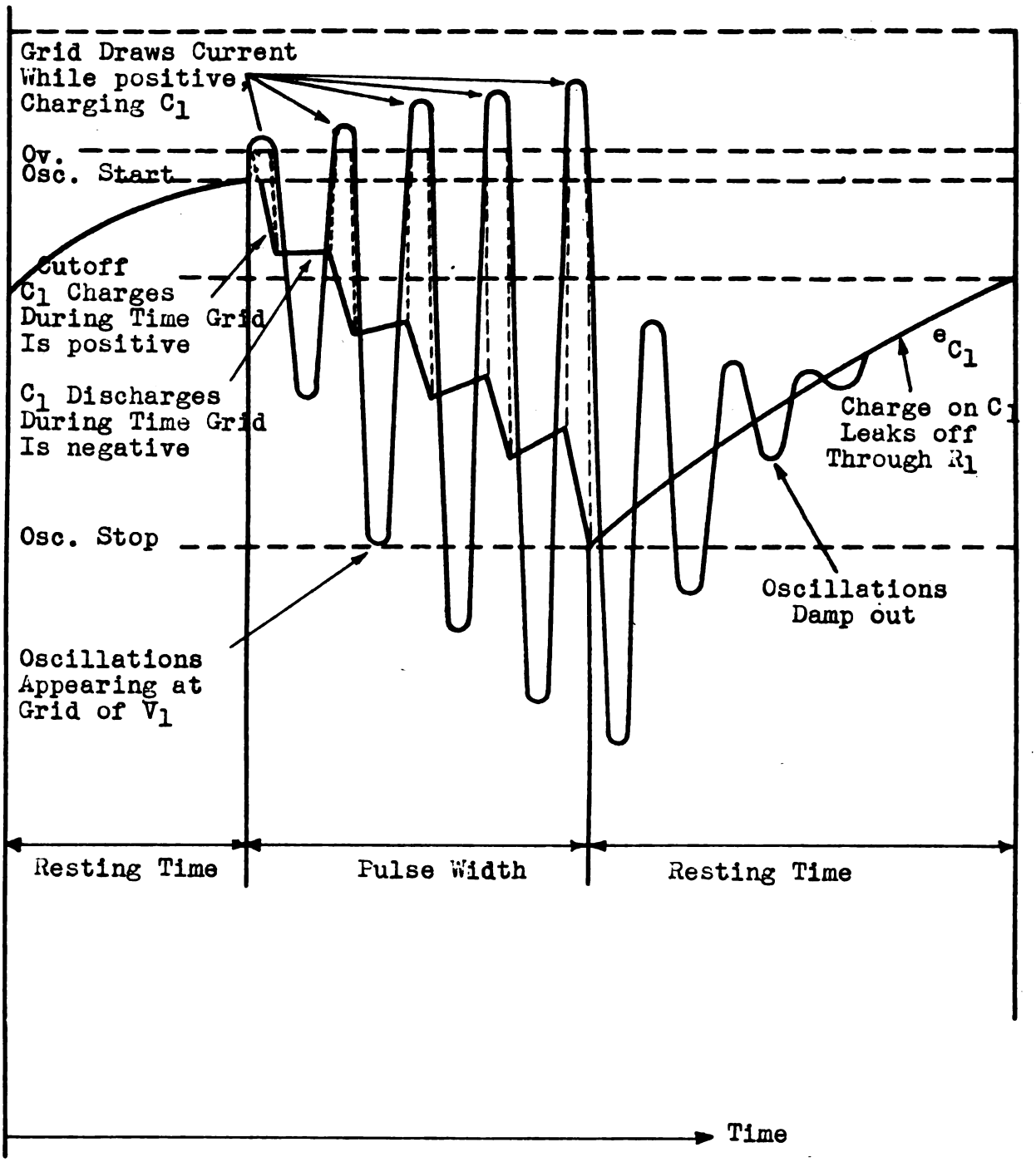

Fig. 5-3: Theoretical Waveforms of a Blocking Oscillator.

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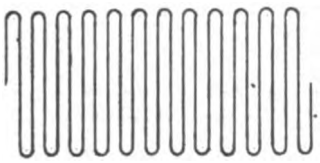
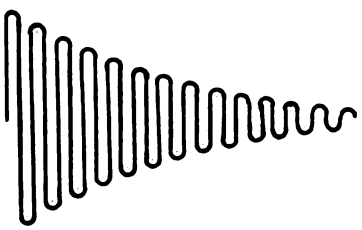
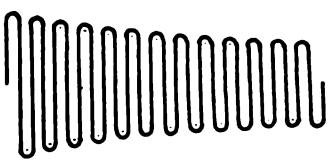
13. The waveforms shown in Figure 4 are those appearing across the tank circuit and since the voltage developed across the tank is the output or usable radio frequency voltage, these are known as RF output waveforms.



(A) Ideal Waveform



(B) Highly Damped Waveform



(C) Slightly Damped Waveform

Fig. 5-4: RF Output Waveforms.

14. Factors Affecting Pulse Width and PRF: The choice of the grid condenser and the grid leak values will be determined by the pulse recurrence frequency desired. The pulse recurrence frequency will then have to be broken down into the pulse width and the resting time. The pulse width is determined by the size of the grid condenser. If this condenser is small in capacity then it will take a comparatively short time to charge up. This results in a narrow pulse. If the grid condenser is large in capacity, then it will take a comparatively long time for the grid bias to build up and the pulse will be a long or wide one. The resting time is determined primarily by the size of the grid leak. If this grid leak has a high resistance, then it will take a long time for the charge to leak off, and as a result, the resting time will be comparatively long. If this grid leak has low resistance, it will take a shorter time for the charge to leak off the grid condenser and the resting time will be shortened.

15. Figure 5 is a diagram of an actual laboratory unit that will be used to study the oper-

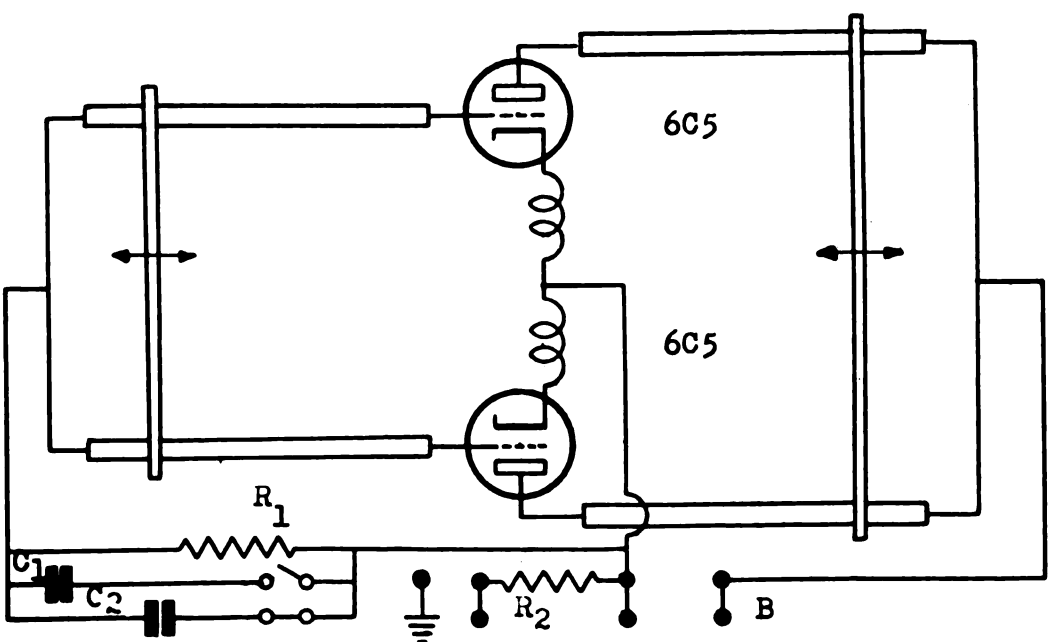


Fig. 5-5: A Laboratory Model of a Blocking Oscillator.

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ation of the RF self-pulsing (blocking) oscillator. Note that the constants of the grid leak and grid condenser have been made variable. In this way it is possible to vary the pulse recurrence frequency as well as the characteristics of this frequency. By varying the value of the grid condenser it is possible to change the pulse width and by varying R_1, the grid leak, it is possible to increase or decrease the resting time. By making R_1 small enough it is also possible to make the oscillator break into CW. With this unit and an oscilloscope the various waveforms and the effects of changing the values of the component parts may be observed.

SYNCHRONIZATION OF THE INDICATOR

16. In Chapter 1, "Basic Concepts of Radar Performance", it was brought out that in Radar systems employing the self-pulsing RF oscillator as the transmitter, the indicator was triggered off as the transmitter fired in order that it could begin measuring the travel time of the pulse at the correct instant. Notice that in Figure 5 a resistance is connected in the negative power supply return lead. Across this resistor there will appear a voltage drop determined by two factors. These factors are (a) the current flowing through this resistance and (b) the value of this resistance. Since the oscillator tubes will draw current only while they are in an oscillating or pulsing state, a voltage drop will appear across this resistance at that time only. Therefore the voltage drops appearing across R_2 will occur simultaneously with the pulse of the oscillator making the RF pulsing and the triggering pulses occur simultaneously. The polarity of these triggering pulses is positive with respect to ground. If negative pulses are also required to trigger off additional equipment such as a Range Marker or Calibrator circuit, these pulses may be obtained by inserting an additional resistance in series with R_2 and B minus and making the ground connection at their junction rather than at the B minus terminal.

GRID LEAK RETURN TO B-PLUS

17. Examination of Figure 2 will reveal that the discharge curve of the grid condenser is not linear. In fact near the point where oscillations start this curve has a pronounced bend. This means that the negative grid voltage is not decreasing linearly. The curve is formed by the RC constants of the grid condenser and the grid leak and therefore will be an exponential curve. As the grid voltage drops to a point where the circuit breaks into oscillation, it is desirable to have this voltage change as linearly as possible; otherwise the circuit may be triggered off before the end of the normal rest, or "off the air" time. This is due to the fact that the discharge curve is nearly "flat" in the critical region where oscillation commences; therefore slight disturbances in the grid circuit may trigger off the oscillator ahead of time.

18. The overall result is an unstable pulse recurrence frequency. Using a tube with a low amplification factor will overcome this condition to some extent, as this type of tube will be less sensitive to these grid circuit disturbances; by returning the grid leak to B-plus, however, much better results can be realized. To obtain this condition in the circuit shown in Figure 5 the grid return lead must be disconnected from the cathode circuit and connected to B-plus. The effect on the slope of the discharge curve resulting from this change is shown in Figure 6.

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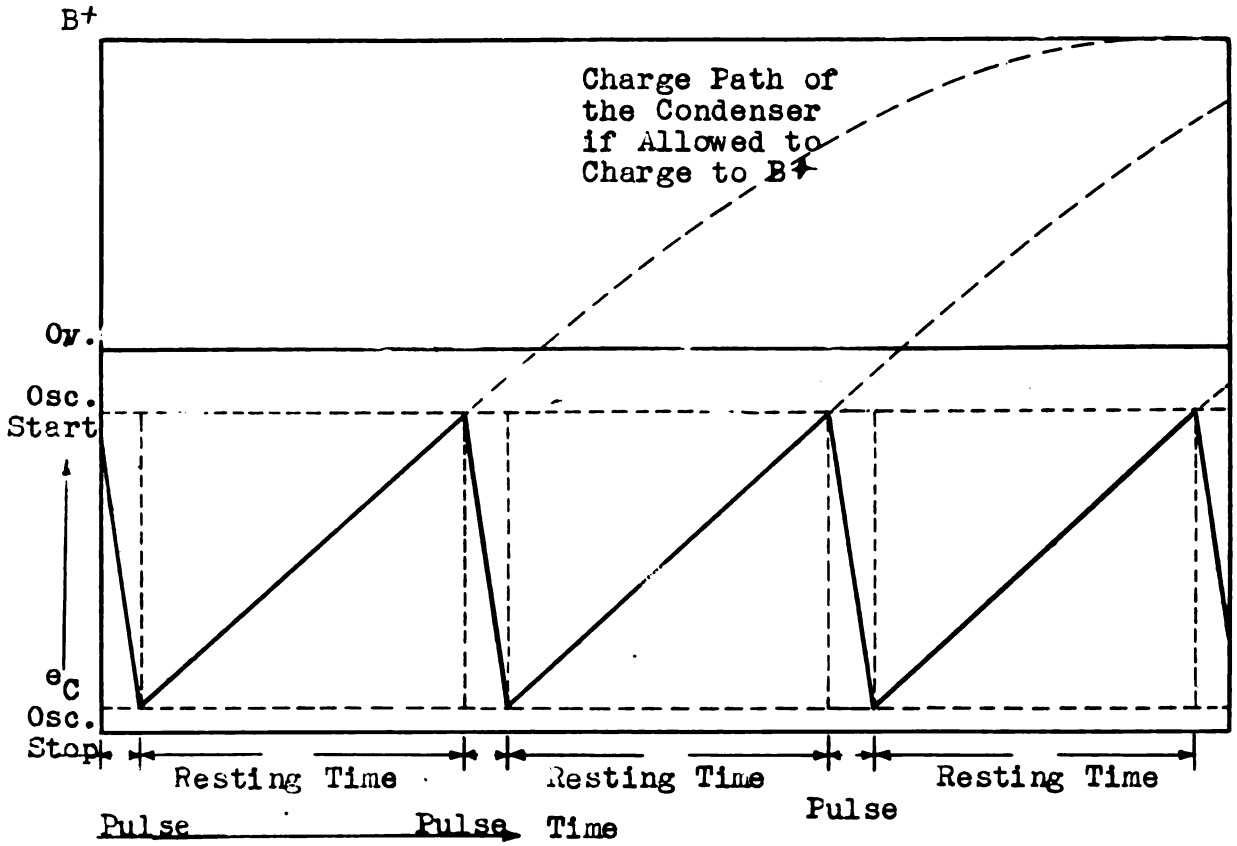

Fig. 5-6: Charge and Discharge Paths of Grid Condenser with Grid Leak tied to B-plus.

19. With the grid leak now returned to the plate potential, or B-plus, the grid condenser "sees" the full B-plus potential during the resting time. This positive potential is opposite in polarity to the charge built upon the near plate of the condenser during the pulsing time. Thus, when the tube blocks, the condenser tends to discharge, then charge in opposite polarity towards the B-plus potential. However as soon as the negative grid voltage decreases to a point where oscillations start, the drain on the grid condenser is stopped and it is once more charged up negatively with respect to ground. The dotted lines of Figure 6 represent the charge path of the condenser if it were allowed to charge to the full plate potential.

20. It should be noted that the same full discharge curve of C_1 exists, but now the initial, more linear portion is used. This means, of course, that the resting time will be shorter and therefore a larger value of grid resistance will have to be employed to obtain the same PRF.

21. The foregoing principles are used in the ASB-ASE and other types of self-pulsing RADAR transmitters. A push-pull circuit is employed for reasons of good frequency stability and high power output. This basic diagram is shown in Figure 7 in a form which is easily analyzed.

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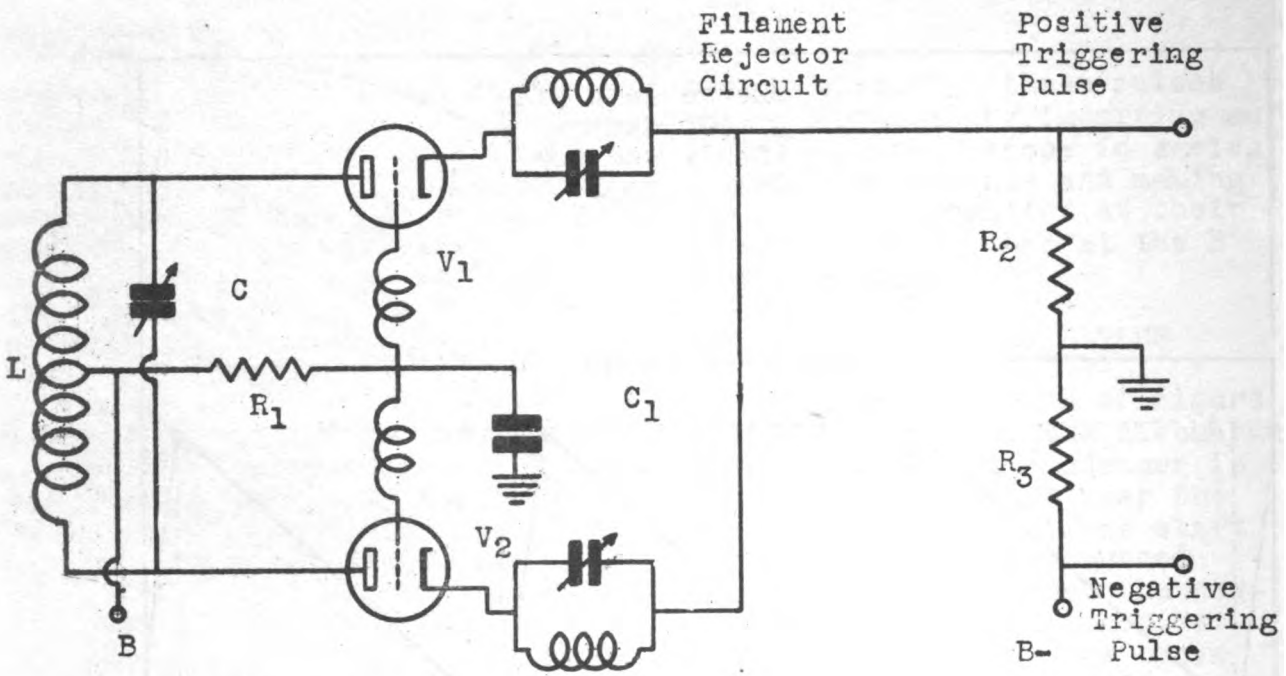

Fig. 5-7: Basic Radar Self-Pulsing Transmitter.

22. In Figure 7 the UHF tank circuit is represented by L and C in the plate circuit. The grid circuit uses an untuned grid coil. Filament rejector circuits are used in the cathode circuit of each tube. This keeps the high-frequency oscillations within the tube and prevents these oscillations from getting back through the power supply and associated circuits. Since one tube will be conducting over a portion of each half of the radio frequency cycle, it is unnecessary to use any by-pass condensers across the triggering pulse resistors R_2 and R_3. A more detailed explanation of the individual transmitters will be presented in later sections where specific types of Radar gear are studied.

23. Synchronizing the Blocking Oscillator: In paragraph 17 it was pointed out that as the grid voltage becomes less and less negative, approaching the level where oscillations start, any slight disturbance in the grid circuit will trigger off oscillation sooner than it would normally have occurred. This characteristic may be used to advantage whenever it is desired to synchronize the blocking or pulsing action of the oscillator with some known frequency standard. The output of this frequency standard is injected into the grid circuit of the blocking oscillator in such a manner that positive alternations (pulses) "trigger" the grid circuit just prior to the time it would normally have gone into oscillation. This requires that the normal pulse recurrence frequency of the oscillator be somewhat lower than that of the frequency standard.

SINGLE SWING BLOCKING OSCILLATOR

24. The single swing blocking oscillator is used primarily as a pulse generator, either freely running or controlled by a synchronizing voltage. As used in Radar, there are two outstanding characteristics which distinguish it from the RF blocking oscillator: (a) Its funda-

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mental frequency is usually within the audio rather than the radio frequency spectrum. (b) An excessively long time constant is used in its grid circuit to cause it to cut-off or block after only one cycle of operation.

25. The circuit consists of a transformer-coupled oscillator with a capacitor in series with its grid, as shown in Figure 8. Although the grid is returned through the grid leak to ground, it could be returned to B-plus. The transformer which couples the plate to the grid circuit must offer nearly perfect coupling and display rather high losses. (See paragraph 30.)

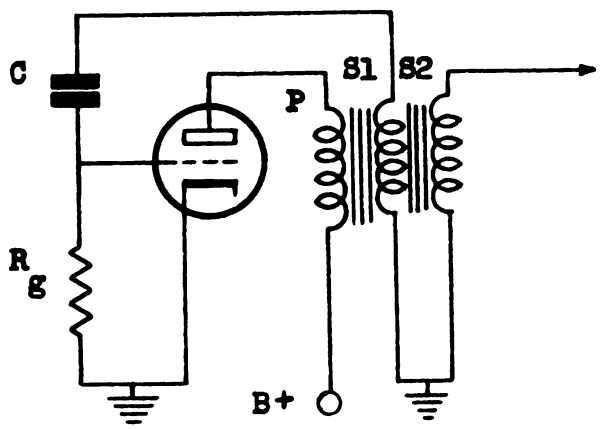

Fig. 5-8: Single Swing Blocking Oscillator.

26. The action of the circuit is as follows: The grid condenser C, charged negatively by a preceding cycle of operation, discharges through Rg. The grid becomes less and less negative until it reaches cutoff at which time the tube begins to conduct. Plate current flowing through the primary of the transformer induces a voltage in the grid winding, which makes the grid less negative, allowing more plate current to flow. This in turn induces a still greater change of voltage on the grid. Thus a cumulative action takes place which subsides when the grid actually becomes positive with respect to the cathode.

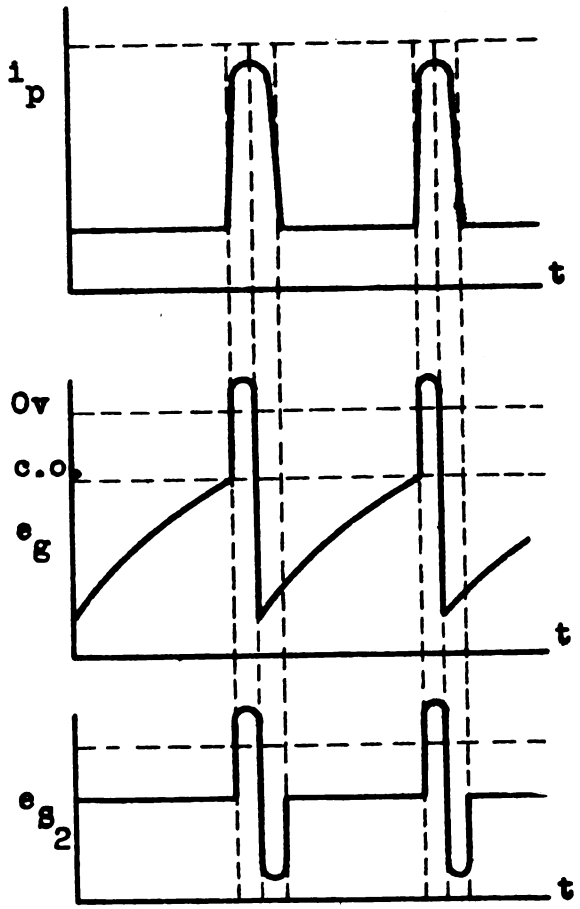

Fig. 5-9: Wave-forms of Single Swing Blocking Oscillator, any one of which may be used as the output.

27. As soon as the plate current ceases to rise, the positive potential on the grid becomes less positive--causing less plate current to flow, which in turn induces a voltage through the transformer depressing the grid still further. This process continues until the grid is driven to cutoff, thus completing a cycle of operation.

28. Oscillation does not start again immediately, however, because the grid current flow (when the grid was positive) built up enough charge on the grid condenser to maintain cutoff until it leaks off through the grid

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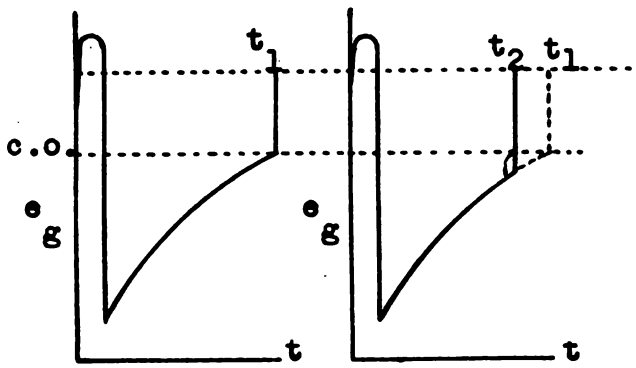
resistor. This action may be followed in Figure 9.

29. The time consumed by the rise and decay of plate current is determined by the resonant frequency of the transformer, but the time between pulses is determined by the value of resistance in the grid circuit and to some extent by the capacity. An oscillator of this type may be readily synchronized by introducing a voltage into its grid circuit as discussed in paragraph 23.



(A) Without Sync Voltage (B) Sync Voltage Applied

Fig. 5-10: Synchronizing Voltage in Grid Circuit.

The slight change in PRF due to synchronization is apparent in Figure 10.

30. The plate voltage pulse may actually show tendency to be followed by a damped oscillation even though the tube is cut-off and inoperative. This is because of the fly-wheel effect of the resonant circuit composed of the transformer inductance and distributed capacity. It is undesirable, since only a single isolated pulse is usually required of the single cycle blocking oscillator; therefore the transformer should have rather high losses in order to damp out these oscillations as soon as possible.

31. By definition, a Repetition Rate Oscillator is any oscillator which is used to determine the pulse recurrence frequency of a Radar transmitter. It is sometimes called "Timing" Oscillator or "Base" Oscillator. The single swing blocking oscillator is satisfactory for this purpose in some Radar equipments, and this constitutes its most important application at the present time.

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CHAPTER VI

Multivibrators

1. The multivibrator is a form of relaxation oscillator consisting of two resistance or resistance-capacitance coupled amplifiers with the output of the second coupled back to the input of the first. It is highly useful in generating the waveforms needed in Radar circuits; being capable of a number of functions applicable in frequency multiplication, frequency division, gate circuits, and the introduction of time delay. For this reason its operation and applications should be understood thoroughly be every Radar Technician. To prepare the student for the standard multivibrator, it is helpful first to deal with two circuits which are similar to the standard multivibrator and which serve as a logical introduction to its basic principles. They are the Eccles-Jordan trigger circuit and the single kick multivibrator trigger circuit.

ECCLES-JORDAN TRIGGER CIRCUIT

2. This special form of multivibrator employs direct coupling between the plates and grids of the two tubes. It is not an oscillator in the true sense but is said to be a circuit possessing two conditions of stable equilibrium. One state of equilibrium exists when V_1, of Figure 1, is conducting and V_2 is cut off; the other when V_1 is cut off and V_2 is conducting. The circuit will remain in either one of these states of equilibrium with no change in plate, grid, and cathode potentials, or plate current, until a trigger pulse is applied to the grids. At this time the circuit switches, or "flops" over, to the other state of equilibrium and remains in that condition until the application of another trigger pulse causes it to switch back to the original state. Thus its operation consists of switching from one state to another by the application of trigger pulses. For this reason the Eccles-Jordan is often referred to as a "flip-flop" circuit.

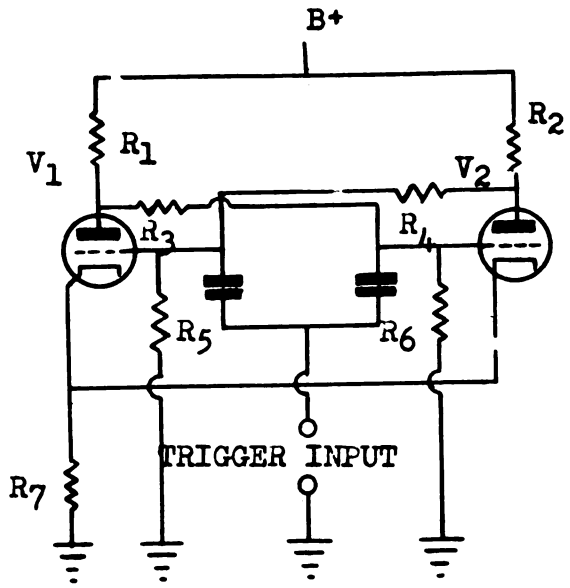

Fig. 6-1: Eccles-Jordan Trigger Circuit.

3. In order to analyze the operation, assume that plate potentials are applied but not the filament voltages. Since the tubes will not conduct the plate to cathode voltages will nearly equal the full supply potential. They cannot quite equal the full B voltage however, inasmuch as there will be a slight current flow through the plate load resistors R_1 and R_2. This is true because R_6, R_3, and R_1 with R_5, R_4, and R_2 form two high resistance voltage dividers in series with the

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power supply.

4. Whenever the filament voltages are applied the cathodes warm up and one tube or the other will begin conduction an instant sooner than the other, or if they do conduct at the same instant, one tube is apt to conduct more heavily than the other. It is inconceivable that any two tubes and their associated circuits can be so nearly identical in manufacture as to begin conduction at the same instant and increase conduction at the same rate.

5. As soon as conduction is established, the plate current of both tubes flows through the common cathode resistor R_7. The IR drop produced establishes both grids at some negative potential with respect to their cathodes. As will be seen later this standing bias will remain reasonably constant during operation. The voltage variations feedback to each grid from the plate of the other tube merely adds to or subtracts from this bias.

6. Assume that both tubes conduct at approximately the same instant but that V_1 conducts somewhat more heavily than V_2. The voltage at its plate becomes less than that at the plate of V_2 because of this heavier conduction. This falling voltage at the plate of V_1 is applied to the grid of V_2 through R_3. This renders the grid of V_2 more negative with respect to its cathode thus decreasing its plate current flow. Its plate potential rises, this increase being coupled through R_4 to the grid of V_1. V_1 grid becomes less negative, allowing more plate current to flow. Its plate voltage falls still more, further depressing the grid potential of V_2. This cummulative feedback action, once underway continues to drive the grid of V_1 in the positive direction and that of V_2 in the negative direction until V_1 is conducting heavily and V_2 is cut off. All the foregoing action occured within a very brief period of time. V_1 will continue to conduct heavily at a fixed value of current and V_2 will remain cut off until a trigger pulse is applied to the grids at which time the circuit will switch to the other state of equilibrium.

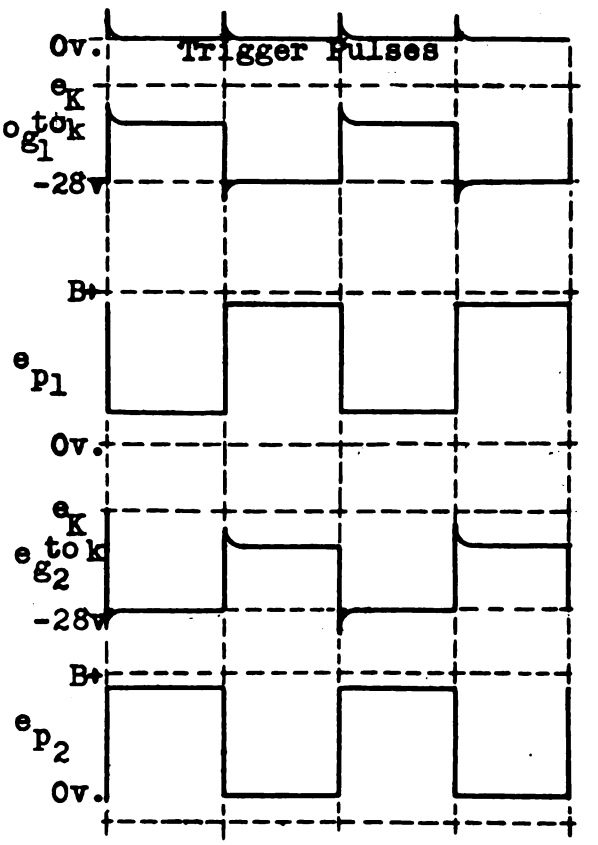

Fig. 6-2: Eccles-Jordan Waveforms.

7. Figure 2 illustrates the action upon the application of a series of positive triggering pulses from some external source. Since V_1 is already conducting quite heavily, the injection of a positive trigger pulse into its grid circuit can have little effect in increasing its plate current flow. It will however, have considerable effect on V_2 as the highly negative potential on its grid will be momentarily removed. Thus V_2 is driven into conduction; its

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plate voltage drops sharply, driving the grid potential of V_1 in the negative direction which causes that tube to conduct less and its plate potential to rise. This rise at the plate of V_1 drives the grid of V_2 still further in the positive direction reinforcing the effect of the trigger pulse. With increased conduction in V_2 its plate voltage drops even more driving the grid of V_1 still further in the negative direction. This cummulative action now drives V_1 to cutoff and V_2 into a steady state of heavy conduction. In like manner the second trigger pulse is effective in bringing V_1 above cutoff and returning V_2 to a state of nonconduction.

8. Negative trigger pulses can be used instead of positive pulses, the only difference being that the negative pulses are effective on the grid of the conducting tube whereas the positive pulses are effective on the grid of the tube that is cutoff. It must be realized that the time required for the tubes to interchange functions is extremely brief as compared to the time interval normally existing between trigger pulses. In Figure 2, the switching or "flop over" time is represented by the vertical sides of the plate waveforms.

9. In a practical working circuit the coupling resistors of the Eccles-Jordan are bypassed by small capacitors to provide somewhat closer coupling between stages. This reduces the switching time by overcoming the attenuation caused by the grid cathode interelectrode capacities. As mentioned earlier, R_7, the cathode bias resistor, is common to both tubes. Since normally only one tube conducts at a time the bias voltage drop across that resistor will be fairly constant. As the tubes interchange functions an increase in current flow in one tube tends to be balanced by a corresponding decrease of plate current in the other.

10. From the foregoing discussion, it is evident that the Eccles-Jordan executes one alternation for each trigger pulse, two pulses being required to bring about a complete cycle. It is possible, however, to accomplish a complete cycle of operation with the application of a single trigger pulse by incorporating certain circuit modifications.

SINGLE KICK TRIGGER CIRCUIT

11. In the single kick trigger circuit of Figure 3 it will be observed that no grid bias is applied to V_2. The grid is returned to the cathode through R_5; therefore under static conditions the grid will be at the same potential as the cathode. This allows V_2 to conduct quite heavily. Its plate current flows through R_4 causing a large voltage drop across that resistor. The voltage thus developed is of sufficient amplitude to cut V_1 off. This

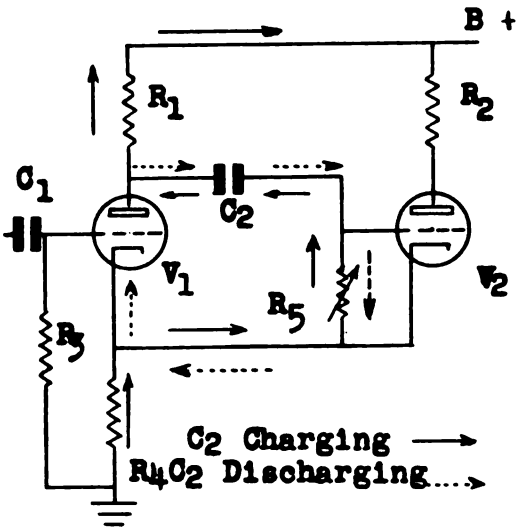

Fig.6-3: Single Kick Trigger Circuit.

then, is the one state of equilibrium that can exist in the circuit; V_1 cutoff, V_2 conducting heavily. The condition will

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continue unchanged until the application of a positive trigger pulse to the grid of V_1. With V_1 cutoff, the voltage at its plate, with respect to ground, is the full supply potential. The voltage at the plate of V_1 is much lower due to its heavy conduction and consequent IR drop across R_2. Since the voltage at the plate of V_2 tends to be the full supply voltage, C_2 will be charged up to that potential through R_4, the grid-cathode path of V_2, and R_1. Its charge and discharge paths are indicated in Figure 3.

12. Figure 4 illustrates the action taking place when positive trigger pulses are applied to the grid of V_1. The positive pulse removes the negative potential from the grid of V_1, driving that tube into conduction. The instant it goes into conduction its plate voltage drops from the full B plus value to a much lower level.

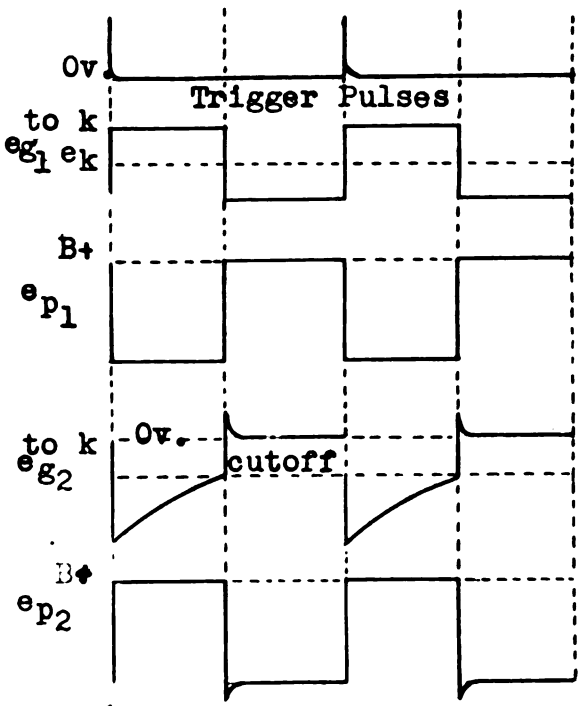

Fig. 6-4: Waveforms of Single Kick Trigger Circuit.

As C_2 was charged up to the higher level, it now tends to discharge down to the new level present at the plate of V_1. But, since its discharge path consists of the low resistance cathode-plate path of V_1, and the high grid resistance of V_2 (R_5) it cannot change its charge immediately, therefore, the entire change of voltage between the cathode and plate of V_1 appears instantaneously at the grid of V_2 across R_5. This drives the grid of V_2 from zero volts with respect to its cathode to the new negative value greatly reducing its plate current flow.

13. The reduction in the plate current of V_2 lessens the IR drop across R_4 thus reducing the grid to cathode voltage of V_1, resulting in a still heavier plate current flow through that tube and a still greater drop in its plate potential. This cummulative process continues until V_2 is cut off and V_1 is conducting heavily.

14. As can be seen from Figure 4, the foregoing action takes place within a very short period of time after the trigger pulse is applied to the grid of V_1. The voltages at the plates of the two tubes have switched to new levels and will remain so as long as V_2 is cutoff. Since the voltage at the plate of V_2 has risen to the B plus value and its plate current stopped it can have no further effect on V_1 via the common cathode coupling as long as it is cut off.

15. Unlike the Eccles-Jordan circuit, the present condition will not continue indefinitely since V_2 is maintained in a blocked condition by the charge on a condenser, C_2. As soon as the discharge current of C_2 decays to such a value that the IR drop produced across R_5 is no longer sufficient to maintain V_2 at cutoff, this condition is terminated. As V_2

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goes into conduction again the additional current drawn through R_4 renders the cathode of V_1 more positive with respect to ground which has the same effect as making the grid more negative with respect to its cathode. This results in an abrupt decrease in plate current through V_1 and consequently an increase in its plate voltage. C_2 now tends to charge up to this new level. This causes the grid of V_2 to become positive, with respect to its cathode, greatly increasing its plate current flow which produces a much larger voltage drop across R_4. The increase in the cathode voltage of V_1 causes its plate current to decay further, resulting in a higher voltage at its plate. C_2 charges rapidly to this new level through the low resistance cathode-grid path of V_2.

16. The cummulative action underway, in a very brief period of time, restores V_1 to its original cutoff state and V_2 into one of heavy conduction. Circuit voltages are now stabilized at the same levels as before the trigger pulse was applied, thus completing a full cycle of operation since the application of the trigger pulse. This return to the original condition was accomplished within the circuit automatically, in contrast to the Eccles-Jordan which required a second trigger pulse. The width of the plate waveforms may be varied over a wide range by changing the value of R_5 which alters the RC time constant of the discharge path of C_2 controlling the period of time that V_2 is cutoff.

17. It is possible to use this circuit as a Radar indicator sweep generator. This may be effected with the addition of a condenser connected between the cathode and plate of V_2. The size of R_2 and the additional condenser must be selected to provide the desired time constant. The output wave is then a sawtooth rather than a square wave.

BALANCED MULTIVIBRATOR

18. The two circuits just described operated only when triggered from some external source. The standard multivibrator does not require external trigger pulses since each tube serves to trigger the other and thus maintain operation. Basically, the multivibrator is considered to be a form of relaxation oscillator because of the fact that its operation depends upon the charging and discharging of condensers through resistances. The circuit for a typical, simplified multivibrator is shown in Figure 5.

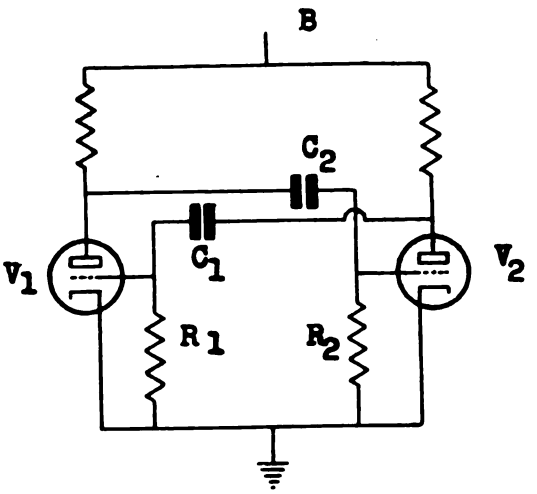

Fig.6-5: The Standard Multivibrator.

19. Consider what happens in this circuit when the power supply is first turned on. At the first instant that power is applied, there will be no plate current flow through either V_1 or V_2 since the cathodes of these tubes are not yet at operating temperature. Thus, since there is no plate current flowing through the tubes, the condensers C_1 and C_2 will charge up to the full supply voltage through the grid leak and plate resistors, if sufficient time elapses.

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20. For purposes of explanation assume that C_1 and C_2 become fully charged to the full plate supply voltage (300 v. in this example) some time before the tubes begin to conduct plate current. If these condensers are fully charged, the grid to ground or grid to cathodepotential must be zero. (Since in any case the voltage from grid to ground must be the difference between the voltage at the plate of the other tube minus the voltage charge on the grid condenser.)

21. Again it may be reasoned that both tubes will not begin to conduct at exactly the same instant, or that both tubes will begin to conduct at exactly the same rate. Suppose V_2 begins conducting plate current sooner than V_1, and because of the voltage drop across the plate resistor due to plate current flow, its plate voltage drops to 200 volts. Since a condenser cannot change its charge (voltage across its terminals) instantaneously, the voltage at the plate of V_2 drops from 300 v. to 200 v. (a change of 100 v.) The grid voltage of V_1 must drop to -100 v. with respect to ground. This is shown at point (a) in Figure 6. This negative potential, since it is greater than that required to cut off V_1, will prevent V_1 from conducting even though its cathode may now be heated up to the temperature required for the normal operation of the tube.

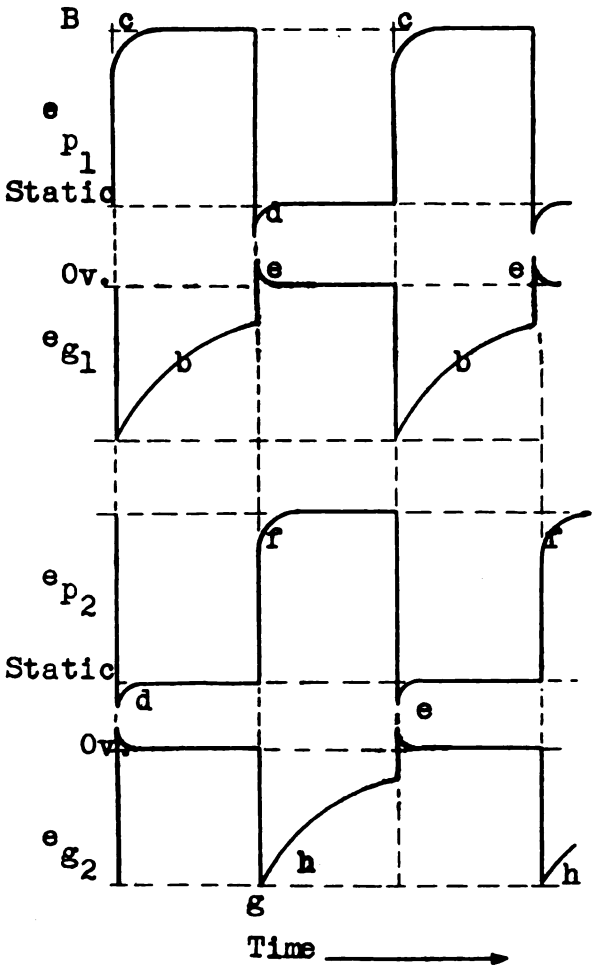

Fig. 6-6: Typical Multivibrator Waveforms.

(a) Grid V_1 driven negative when plate voltage of V_2 dropped.

(b) Grid V_1 becoming less negative as C_1 discharges through R_1 and V_2.

(c) Plate voltage does not rise to B plus instantaneously due to IR drop across plate resistor caused by charging current of C_2.

(d) Plate voltage drops below static level because grid was driven positive (above zero).

(e) Grid driven positive by rise of plate voltage of other tube.

(f) Plate voltage does not rise to B plus instantaneously due to IR drop across plate resistor caused by charging current of C_1.

(g) Grid V_2 driven negative when plate voltage of V_1 dropped.

(h) Grid V_2 becoming less negative as C_2 discharges through R_2 and V_1.

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22. Since the charge on C_1 is 300 volts and the voltage at the plate of V_2 is only 200 volts, with respect to ground, it is evident that C_1 must discharge by 100 volts. Electrons cannot flow from grid to cathode in any vacuum tube so the discharge path of C_1 must be down through the grid-leak resistor R_1. It will be recognized that while C_1 is discharging, electrons must be transferred from the left-hand plate of C_1 (Figure 6) around to the other plate, and that as V_2 is conducting heavily its resistance from cathode to plate is low. This provides a path for electron flow as C_1 discharges; namely, down through R_1, up through V_2, to the other plate of C_1. This discharge path is shown in Figure 7.

23. Now the negative voltage (-100 v.) appearing at the grid of V_1 was initially the difference between the voltage at the plate of V_2 (200 v.) and the charge of C_1 (300 v.). As C_1 discharges exponentially, this voltage difference will decrease; or, in other words, the grid will become less negative as C_1 discharges. This is shown at (b) in Figure 6.

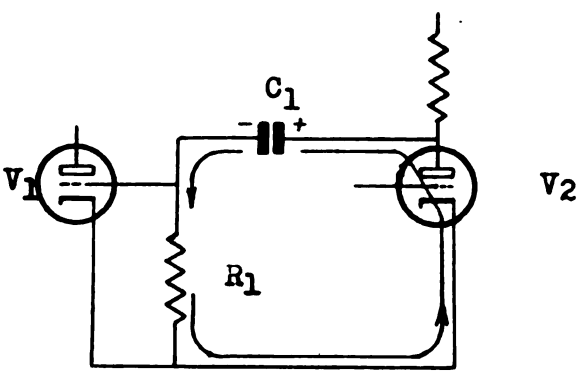

Fig. 6-7: Discharge Path of C_1.

24. As C_1 discharges, the grid of V_1 becomes less negative and will eventually rise above cutoff, allowing plate current to begin to flow through V_1. Plate current flow will cause an IR drop to develop across the plate resistor of V_1 which in turn will drop the voltage at the plate of V_1 to some value less than the supply voltage. As in the case of V_2, assume that this new level of plate voltage is 200 volts.

25. It will be recalled that C_2 also was initially charged up to 300 volts and so when the voltage at the plate of V_1 drops by 100 volts, the grid of V_2 will drop by 100 volts. In other words, the grid of V_2 will drop to a potential of -100 volts with respect to ground and V_2 will be cut off.

26. When V_2 is cut off by the action just described, there will be no plate current flowing through the plate resistor of V_2, the voltage at the plate of V_2 will rise to the supply potential (300 v.) and C_1 will start to recharge. This sudden rise in plate voltage must appear on the grid of V_1 as C_1 cannot change its charge instantly. Thus, the grid of V_1 becomes positive with respect to the cathode. C_1 will charge mainly through the path offering the least resistance to electron flow and since the resistance between cathode and grid of any tube is low when the grid is driven positive with respect to the cathode and grid current is flowing, it follows that the condenser C_1 will charge through V_1. The complete charge path of C_1 is shown in figure 8.

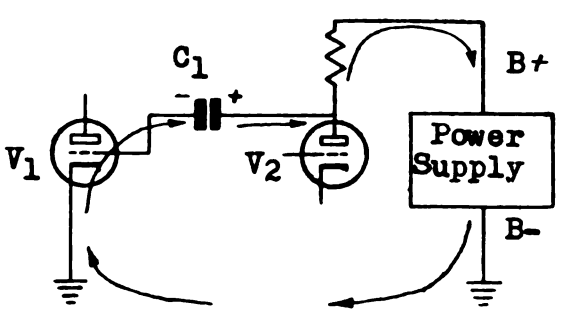

Fig. 6-8: Charge Path of C_1

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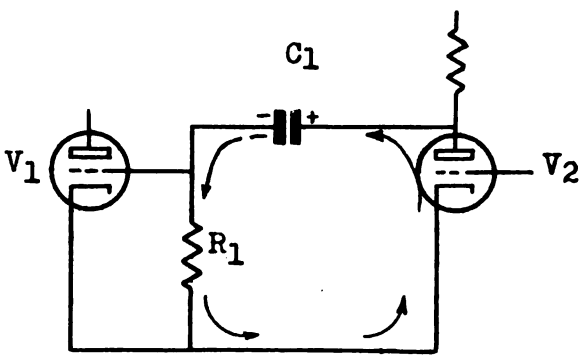

Fig. 6-7: Discharge Path of C_1.

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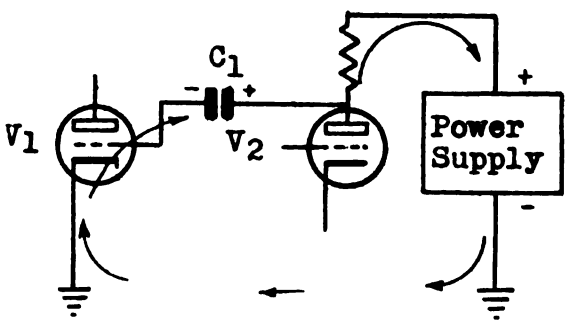

Fig. 6-8 Charge Path of C_1

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of V_1 will rise exponentially as C_2 charges, and will be equal to the supply voltage only when C_2 is fully charged, (point "c" Figure 6).

32. At low frequencies, this time required for the plate voltage of V_1 to rise to the supply potential is such a small percentage of the time V_1 is cutoff that the output voltage may be an excellent rectangular wave. As the frequency is increased, however, the length of time required for the plate voltage to rise becomes a greater percentage of the time the tube is cutoff and so this effect becomes noticeable. Reducing the size of the plate resistors reduces the rounding effect of the plate voltage waveforms. In other words, the RC time constant for the charge of C_2 is reduced but this also reduces the output. Reducing the size of C_1 or C_2 would reduce this time and give a better square-wave at each plate but this decreases the grid circuit capacity, thus increasing the frequency.

33. Realizing that it is the charge on a condenser in the grid circuit which actually causes each tube to be cut off in turn, it should be evident that the length of time either tube is held in a cutoff condition can be changed by changing the RC time constant of the grid circuit. If the time constants of both grid circuits are increased, it is evident that the time that each tube is cut off will be greater and hence the frequency will have been decreased. As a rough approximation, the time required for C_1 to discharge is considered to be R_1C_1 seconds and the time required for C_2 to discharge is R_2C_2 seconds; the total time for one cycle being R_1C_1 plus R_2C_2 seconds. The frequency of oscillation is the reciprocal of the time for one cycle:

$$f = \frac{1}{R_1C_1 + R_2C_2}$$

From the above discussion it may be seen that in order to change the frequency of operation it is necessary only to change the RC time constant of either one or both of the grid circuits.

34. If the RC time constant of both grid circuits is the same, the length of time each tube is cut off is the same This is commonly referred to as a "balanced condition". In this case, the time width of the positive pulse on either plate is the same as the length of time between each pulse.

UNBALANCED MULTIVIBRATOR

35. In some Radar applications of the multivibrator, it is desirable to obtain a pulse of short time duration with a longer period of time between pulses. To do this it is necessary to make the time constant of one grid circuit greater than the time constant of the other.

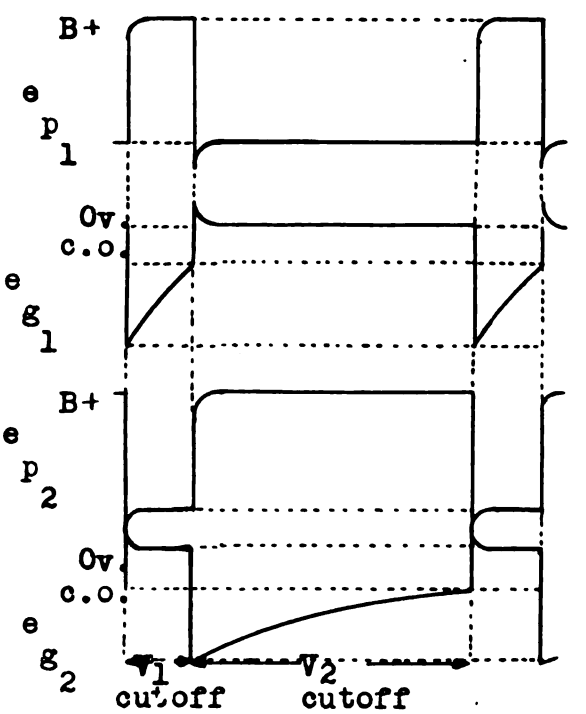

Fig. 6-11: Waveforms of an Unbalanced Multivibrator.

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Thus, the time of cutoff of one tube is greater than the time of cutoff of the other tube. These time relations are illustrated by the waveforms of Figure 11. In the case illustrated in Figure 11, the RC time constant of the grid circuit of V_1 is approximately one fourth that of the time constant for the grid circuit of V_2. This is commonly referred to as an "unbalanced" condition.

ELECTRONIC SWITCH

36. There are a number of instances in Radar installations where a multivibrator, synchronized with the local repetition rate control, is used to sensitize or desensitize various circuits during some portion of the operating cycle. To accomplish this, the square wave output of the multivibrator, taken from either plate or cathode, is applied to either grid or cathode of one or more tubes of the circuits to be gated, driving those tubes into conduction or cutoff as the case may be. The RC time constants of the multivibrator are adjusted until the width of its output pulse persists over the desired period of time.

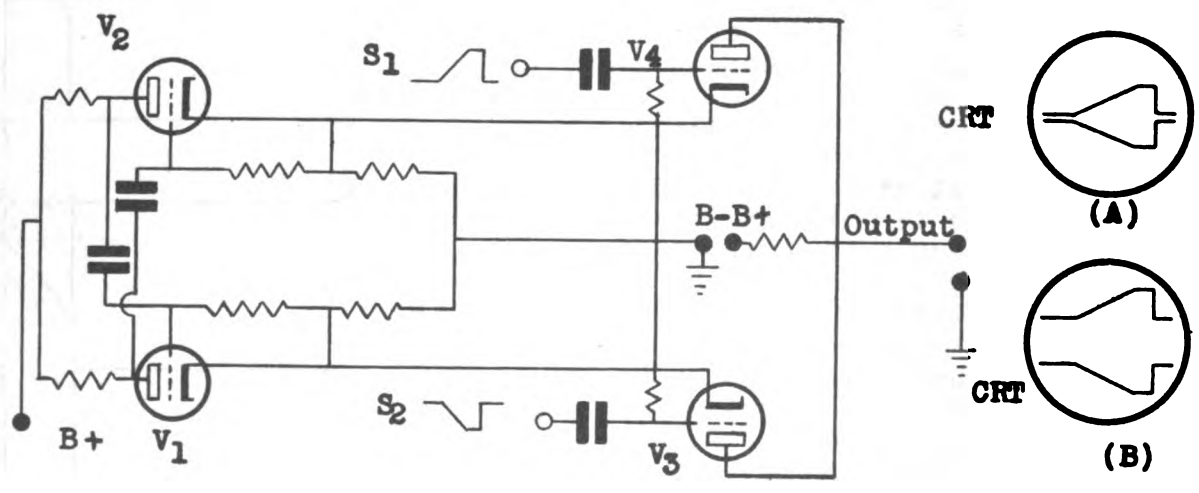

Fig.6-12: Simple Electronic Switch

37. Figure 12 illustrates the application of a multivibrator as an electronic switch to permit simultaneous observation of two different waveforms on a single cathode ray screen. Obviously, signals S_1 and S_2 could not be applied to a single pair of vertical deflecting plates at the same time and produce any satisfactory results. however, if it is arranged to apply first one and then the other, switching back and forth rapidly enough, it would appear that both signals were continually present on the screen.

38. In operation both signals are present at the grids of V_3 and V_4, however, only one at a time appears at the output. This is due to the switching action of the multivibrator consisting of V_1 and V_2. Assume that V_2 is conducting. The positive square wave potential developed at its cathode is applied to the cathode of V_4 driving it to cutoff thus preventing S_1 from getting through to the output. Meanwhile V_1 is not conducting and the only potential present at its cathode is that caused by the normal plate current flow of V_3, through the common cathode resistor. V_3 then is conducting and passing S_2 on through to the output. As the multivibrator tubes exchange functions,

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V_3 and V_4 likewise change, V_3 becoming cutoff and excluding S_2 while V_4 conducts and passes S_1. This switching is done rapidly enough that the eye sees the scope pattern at "A" where the two traces are superimposed, one above the other.

39. A further improvement can be made if the switching potentials at the cathodes of the multivibrator are also superimposed upon the vertical position voltage at the oscilloscope. This would cause the trace to move abruptly up or down each time switching takes place and it would retain its level on the screen for the duration of the square wave at the multivibrator cathode. The two traces would then appear separated as at "B" of Figure 12.

SYNCHRONIZATION

40. Another feature of a multivibrator circuit often applicable in Radar is that it may be synchronized very readily to some control frequency which is injected into the circuit. For example, if it were desired to have the multivibrator operate at 800 cycles per second, an 800 cycle voltage may be injected into one of the grid circuits and the amplitude adjusted so that, as the grid voltage is rising toward cutoff, the injected voltage will raise the grid potential enough to "trigger" the circuit just before its normal time. In this way stability of the multivibrator frequency may be obtained which will be as good as the frequency stability of the device supplying the control voltage.

SUSTAINING MULTIVIBRATOR

41. The sustaining multivibrator, or Franklin oscillator, employs a multivibrator type circuit to sustain oscillations in an LC tank. In Figure 13, Sw_1 and Sw_2, are included merely to aid in the analysis of the circuit. Assume that both switches are open. This isolates the circuit of V_2 and V_3 which is essentially an ordinary RC coupled multivibrator. The circuit will then oscillate in the usual manner producing square waves at the plates of both tubes. Now consider the action when Sw_2 is closed. This connects LC with its low DC resistance in parallel with R_3, or in other words, between the grid of V_2 and ground. With such a low resistance present, the grid of V_2 can no longer be blocked in the usual manner and the multivibrator ceases to function as such. However, the instant Sw_2 is closed the instantaneous potential present across R_3 due to previous multivibrator action is sufficient to shock LC into oscillation at its resonant frequency (Sw_1 is still open). Its resonant frequency is usually many times higher than that at which the multivibrator alone would operate.

42. The shock excited oscillations in LC normally would be damped out within a short space of time due to the usual losses encountered in a tuned circuit. However, the presence of the multivibrator circuit, which now acts merely as a two stage regenerative amplifier, feeds back sufficient energy into LC to sustain its oscillations at the resonant frequency of the tank, and not at the frequency determined by the RC constants in the grid circuits of the multivibrator.

43. To examine the operation in more detail assume that the leading slope of the first sine wave alternation developed across LC drives the grid of V_2 in the negative direction. This causes the plate current flow to decrease and the voltage at the plate of V_2 to rise in the pos-

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itive direction. This positive going voltage is applied to the grid of V_3 increasing the plate current flow of that tube causing its plate voltage to fall in the negative direction. The negative going voltage is coupled back to the grid of V_2 thus reinforcing the oscillatory action of LC and producing a still more negative potential at the grid of V_2. This one way action will not continue indefinitely since it must follow a sinusoidal curve due to the flywheel action of the LC tank. Thus voltage changes across LC are augmented by feedback from the multivibrator circuit which sustains the oscillations in the tank at a high amplitude.

45. The Franklin oscillator just described is used in some range marker systems (Chapter XVIII, Paragraph 6). The sine wave oscillations across LC are passed through a limiter amplifier, a sharpening amplifier (actually another shock oscillator circuit), and a biased cathode follower to produce sharp positive pips to be applied to a PPI or similar type indicator CRT. Obviously, some method is required to start and stop the oscillations in the tank so that they coincide with the time-duration of the indicator sweep. This gating action can be effected by means of V_1. With Sw_1 closed, a heavy current flows through L and the cathode-plate

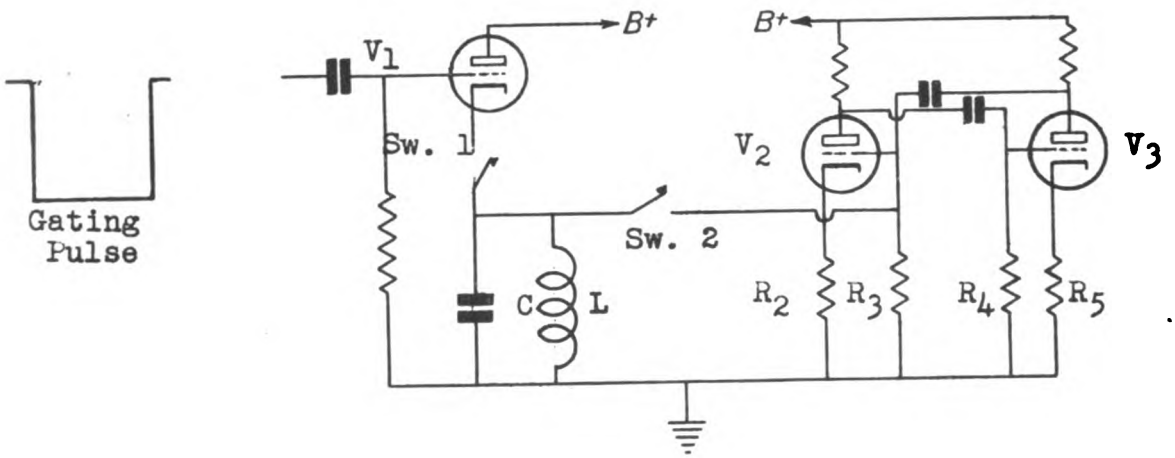

Fig. 6-13: Sustaining Multivibrator.

44. The grids of the multivibrator tubes should not be allowed to go positive with respect to their cathodes during operation, particularly the grid of V_2 since its conducting cathode-grid path would constitute a low resistance in parallel with LC and would probably prevent sustained oscillation because of the heavy dampening effect introduced. Therefore, cathode resistors, R_2 and R_5 are employed with V_2 and V_3 to bias those tubes to the more linear part of their characteristic $e_g - i_p$ curves.

path of V_1. In effect the low impedance of the heavily conducting tube, in series with the neglible impedance of the power supply, is in shunt with LC. This introduces such heavy losses that oscillations in LC are impossible even with the aid of the multivibrator circuit.

46. To gate the oscillator a negative square wave is applied to the grid of V_1 and is of sufficient amplitude to cut it off. The duration of

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the indicator sweep and the leading edge of the square wave must correspond to the beginning of the indicator sweep. V_1 is then cut off by the square wave the instant the trace begins and the abrupt secession of current flow through L shocks LC into oscillation. The first alternation appearing across LC is negative with respect to ground and coincides with the start of the indicator sweep. Oscillations continue for the duration of the sweep being interrupted abruptly at its conclusion as the negative gating pulse is removed from the grid of V_1. These oscillations, normally damped, are sustained at a constant amplitude by employing the Franklin oscillator as shown in Figure 12.

47. Another modification of the multivibrator in which the feedback from the second stage to the first occurs through the cathode circuit is sometimes employed to produce range markers on the Radar indicator screen. This is known as the "Range Marker Multivibrator" and is described later in Chapter XVIII, Paragraph 7.

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CHAPTER VII

Transmission Lines And Antennas

TRANSMISSION LINES

1. A transmission line is any arrangement of two parallel conductors used to convey radio frequency energy from its source to the device in which that energy is to be usefully expended, as from a transmitter to an antenna or from an antenna to a receiver. Such lines must be designed to transmit energy from one point to another with minimum loss either by radiation, or by heating in resistances or in neighboring conductors or dielectrics. There are three general types of tranmission lines employed in Radar. They are the open wire line, the shielded pair and the coaxial line.

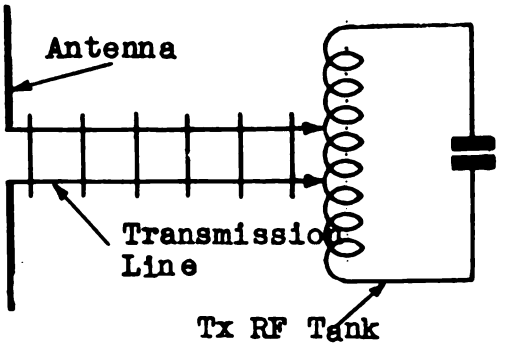

Fig. 7-1: Open Wire Line Linking a Transmitter RF Tank Coil With an Antenna.

2. The open wire line is rather simple in construction; consisting of two open, parallel wires separated at intervals by insulating spacers. The spacers are made of a variety of insulating materials of which the plastic, polystyrene is typical. The outstanding advantages of such a line are its simplicity and low cost. On the other hand its disadvantages are rather serious for aeronautical work. First, it is hardly compact or flexible enough to be used within the crowded confines of an airplane. Second, considerable energy would be absorbed from the line by the fuselage or other nearby metallic objects. For these reasons the open line is not often used in airborne Radar, the shielded pair and the coaxial line being more adapted to aircraft installations. However, the open line does serve to illustrate many of the basic principles of all transmission lines some of which will be discussed at this point.

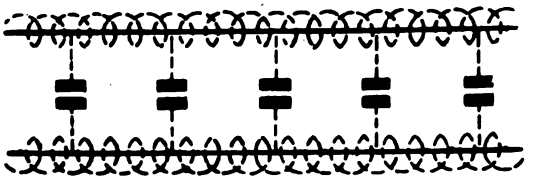

Fig. 7-2: Distributed Constants of a Transmission Line.

3. Transmission lines might be further defined as those circuits whose constants (resistance, inductance, capacity and leakage) are evenly distributed throughout their length. It is an accepted fact that even a piece of straight wire has a certain amount of distributed inductance. Since a transmission line consists of two conductors separated by a dielectric, it follows that there is a certain amount of capacity between the conductors distributed along their length. In effect, then, there is distributed inductance

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acting in series all along the line and capacity distributed across the line as visualized in Figure 2. As every unit length has its capacity and inductance, any wave traveling on that line is continually delayed or retarded in phase. After some number of unit lengths have been traversed the wave will have been retarded a complete 360 degrees in phase--this length is called a wavelength and is especially important since it largely determines the action of the line.

4. Characteristic Impedance: The presence of inductance and capacity along a transmission line is responsible for the existance of one of its most important properties, the characteristic impedance, Zo sometimes called the surge impedance. The characteristic impedance is the impedance which an infinitely long line would present to an electrical impulse induced in the line, and is important in determining the operation of the line in conjunction with the apparatus to which it is connected. Zo is a pure resistive impedance, its value in ohms being determined by the square root of the ratio of the inductance to capacity per unit length of line.

$$Z_o = \sqrt{\frac{L}{C}}$$

For all practical purposes it is independent of the total length of the line or the frequency transmitted. Inasmuch as the amount of inductance and capacity per unit length of line are largely determined by the wire size and spacing it is much easier to calculate the impedance of an unknown line from these physical dimensions. For an open pair line:

$$Z_o = 276 \log \frac{2D}{d}$$

where "D" is the spacing center to center from one conductor to the other, and "d" is the diamter of the conductor.

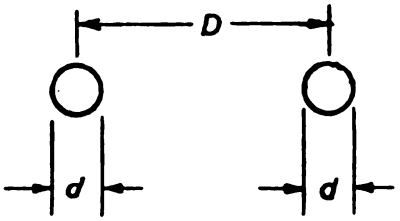

Fig. 7-3: Dimension of Open Pair Line Used in Computing Z_o

"D" and "d" may be measured with calipers and if an impedance chart with D/d plotted against Z_o is available, the determination of the unknown Z_o may be simplified without having to solve the formula. In many instances it is possible to obtain the manufacturers specifications which may be attached to the spool on which the line is wound.

5. Shielded Pair: The shielded pair line consists of two parallel conductors separated from each other and surrounded by an insulating dielectric material, such as the plastic copaline, and is contained within a copper braid tubing which acts as a shield for the conductors.

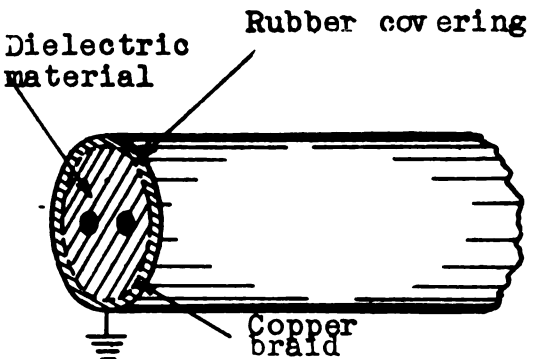

Fig. 7-4: End View Shielded Pair Line

This assembly is covered with a rubber or flexible composition coating to protect the

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line against moisture and friction. Its outward appearance is much like that of an ordinary power line.

6. The most outstanding advantage of the shielded pair is the fact that the two conductors are "balanced to ground", i.e., the capacity between each conductor and ground is uniform along the entire length of the line. This is effected by the grounded shield which surrounds the conductors at a uniform spacing throughout their length. To appreciate this improvement consider the open pair or unshielded line. If radiation from such a line is to be prevented the opposing current flow in each conductor must be equal in amplitude to set up equal and opposite magnetic fields and thereby cancel out. This condition may be obtained if the line is well in the clear of all obstructions; but suppose the line runs near some grounded or conducting surface, and that one of the two conductors is nearer that obstruction than the other. A certain amount of capacity will exist between the two conductors and the conducting surface over a length of the line depending upon the size of the obstruction. This capacity acts as a parallel conducting path for each half of the line causing a division of current flow between each conductor and the interfering or stray capacity. Since one conductor is nearer the obstruction than the other the division of current flow will be greater on one line, resulting in an inequality of current flow in the two conductors, incomplete cancellation, and radiation.

7. Thus it can be seen that the shielded pair, because of its greater flexibility and balance, is more suited for aircraft installation than the open pair. The principal use of the shielded pair, at the present time is in the older meter search equipment, between the transmitter and the antenna. The trend in more recent equipments is to employ coaxial line or waveguide.

8. Since the spacing between the two conductors "D", Figure 3, is considerably less than that of an open pair the capacity per unit length is increased. There is a further increase in capacity due to the presence of the insulating material between the conductors which has a higher dielectric constant than air. The increased capacity results in a lower characteristic impedance. The Z_o of the shielded pair may be determined by the same formula given for the open pair if the results obtained are multiplied by the "propagation constant", P_k, sometimes called the velocity constant. This is necessary since the increased capacity of the shielded pair causes it to retard a wave more per unit length than does the open line. The propagation constant is equal to the square root of the reciprocal of the dielectric constant. If the dielectric constant is not known the propagation constant may be determined by the use of slotted line equipment.

9. Coaxial Line: The small, lightweight, coaxial or concentric line is the most efficient and widely employed type of line in use at the ordinary ultra high frequencies. There are two general types used in airborne Radar, the first or rigid type consists of a solid conductor mounted along the axis of an outer metal tube which is the other conductor. The spacing between the two is maintained by ceramic or plastic beads placed at intervals within the line. The line is usually sealed and filled with air through a valve at about sea level pressure, or is exhausted of air and filled

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with dry nitrogen gas at low pressure. In either case the purpose is to minimize the collection of moisture and prevent arcing over between the conductors at high altitudes. The second, flexible, type of coaxial line consists of a solid or stranded conductor mounted along the axis of a tubular, outer metal braid with continuous rubber or flexible plastic insulation between the two conductors or hard plastic insulation such as polystyrene in the form of a continuous series of beads.

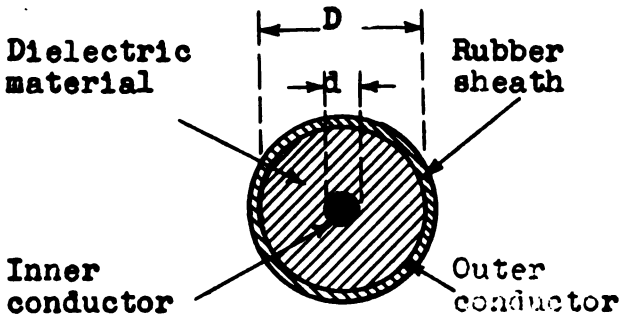

Fig. 7-5: End View of Coaxial Line.

10. The outer conductor in addition to its ordinary function acts as a shield for the RF energy passing along the line. Due to the usual skin effect at ultra high frequencies the energy on the inner conductor travels along its outer skin. However, the energy on the outer conductor travels along its inner skin. This peculiar fact may be attributed to the usual skin effect plus the fact that at corresponding points on the two conductors the instantaneous potentials are equal and opposite and therefore attract each other. Since the RF energy is on the inside of the outer conductor the outside is said to be "cold" and acts as a shield preventing radiation of the RF energy within the cable and undesirable pickup from interfering sources.

11. The characteristic impedance of the coaxial line, may be determined from its physical dimensions by

$$z_o = 138 \log \frac{D}{d}$$

where "D" is the inside diameter of the outer conductor and "d" is the outer diameter of the inner conductor. In applying this formula to the rigid type of line the propagation constant may be assumed to be nearly the same as that of free air. In the case of the flexible line with its solid dielectric, the results obtained by the formula must be multiplied by the propagation constant since the velocity of a wave in such lines may be reduced to 75% or less of that in free air.

STANDING WAVES

12. Figure 6 depicts the voltage distribution and attenuation along a line that for all practical purposes is infinitely long as compared with the wavelength of the RF energy that is supplied by the generator. For convenience this drawing and others that are to follow are illustrated with open pair lines although the basic principles apply as well to the other types.

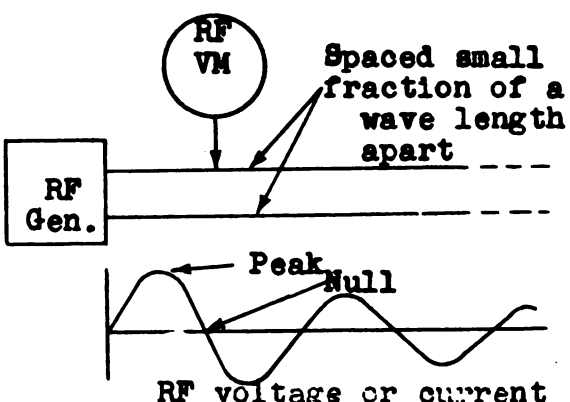

Fig. 7-6: Voltage Distribution On An Infinitely Long Line.

13. To the RF voltmeter

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placed at some point along the line there appears a rapid succession of voltage maxima and minima. The voltmeter is designed to indicate some average value of either the positive or the negative alternations. As the meter is moved down the line the magnitude of the voltage indicated slowly decreases due to the attenuation of the signal as the distance from the source increases. Eventually a point is reached where the voltage reading will be zero. An infinitely long line therefore reflects no energy back to the source; it is all lost or dissipated in the line. The attenuation is due to radiation, heating of the wires and leakage through the air or other insulating material between the wires. This loss of energy along the line takes place logarithmically, and is measured in decibels per unit length.

14. Radiation loss from the line is minimized when the two conductors are spaced a small fraction of a wavelength from each other allowing the opposing electro-magnetic fields to cancel each other. It is natural for these fields to be opposing each other since the current which cause them are always flowing in opposite directions at corresponding points along the line. This follows from the simple fact that the two conductors are tied to the opposite terminals of the generator. The two other losses mentioned can be reduced to some extent by employing conductors with low RF skin resistance together with high quality insulating material and insuring that moisture is not allowed to get into the line.

15. If a line of some finite length is terminated in a resistance equal to its Characteristic Impedance any RF energy applied to the input end will be dissipated in that resistance and none will be reflected back to the source. To the source the line presents an impedance equal to its characteristic impedance just as if it were an infinitely long line. If the length of line is but a few feet the line loss will probably not be very great and the RF voltmeter reading will be practically constant when moved along the line.

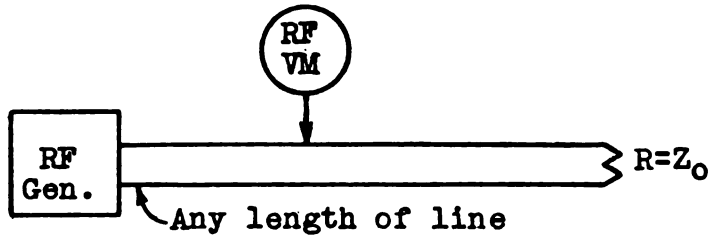

Fig. 7-7: Line Terminated In A Resistance Equal To Its Characteristic Impedance.

16. If a line is terminated in a short circuit there is no load resistance in which to dissipate the energy therefore it is reflected back toward the source. The reflected voltage and current waves from the shorted end as they travel back along the line become in phase and out of phase with the outgoing waves from the RF generator. This results in the two components, the original and the reflected waves, cancelling out and reinforcing each other at periodic intervals along the line. The position of these standing waves can be checked with the RF voltmeter. As indicated in Figure 8, cancellation takes place at any even number of quarter waves from the shorted end resulting in voltage minima while reinforcement takes place at odd quarter wave intervals from the end resulting in voltage maxima. Current maxima and minima are displaced a quarter wave or 90 electrical degrees from the voltage maxima and minima. Note that the first voltage minimum and

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current maximum occurs at the shorted end. This is logical since high current and low voltage are to be expected at a short circuit.

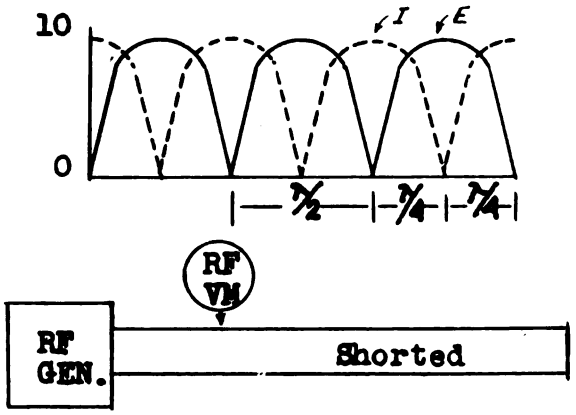

Fig. 7-8: Line Terminated in A Short Circuit.

17. If the line is terminated in an open circuit the position of the standing waves is reversed from that of Figure 8. As might be expected there is no current flow at the open end and the voltage builds up to a maximum. Voltage maxima then exist at any even number of quarter waves from the end while current maxima appear at any odd number of quarter waves from the end.

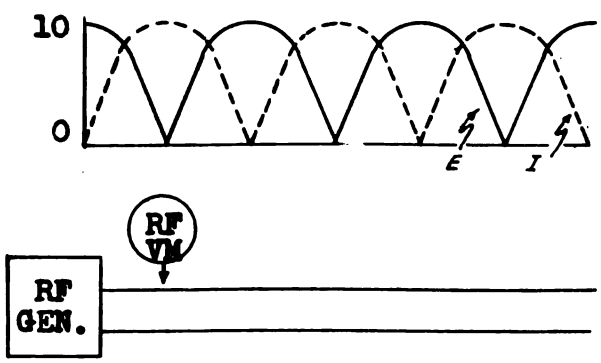

Fig. 7-9: Line Terminated In An Open Circuit.

18. It has been pointed out that if a line is terminated in a resistance equal to its characteristic impedance there are no reflections from the open end and therefore no standing waves.

Now consider a condition in which a line is terminated in a resistive load higher than Z_o.

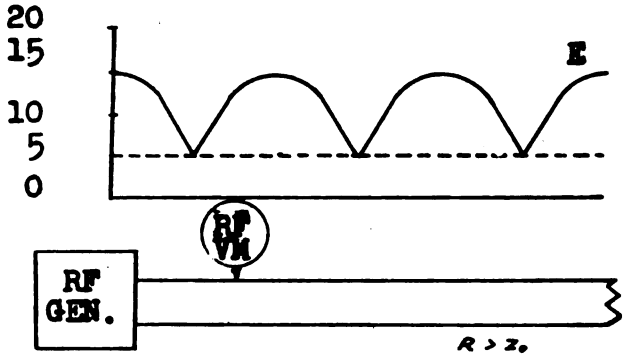

Fig. 7-10: Line Terminated In A Resistance Higher Than Its Characteristic Impedance.

19. The line impedance and the load are not matched, thus a certain amount of energy will be reflected from the end. Since the load has a higher resistance than Z_o it resembles an open circuit rather than a short circuit, therefore the voltage at the termination is maximum and the current is minimum. Since the amount of energy reflected is not as great as that leaving the generator the reflected wave does not aid or oppose the waves from the generator as much as with an open circuited or short circuited line and the standing waves are of less amplitude. The amplitude of the standing waves varies directly with the degree of mismatch at the terminating end. When the mismatch is greatest, as with an open circuited or short circuited termination, the amplitude of the standing waves is greatest. When the line is terminated in its characteristic impedance the standing wave amplitude is zero.

20. Standing Wave Ratio: Frequently it is desirable to use some term to express the standing wave amplitude. The term in common usage is the

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standing wave ratio which is

$$\text{Standing wave ratio} = \frac{E\ MAX}{E\ MIN}$$

In Figure 10 E_{max} is 15, E_{min} is 5. The standing wave ratio is then 15/5 or 3 to 1. This ratio also indicates the degree of mismatch at the termination. The load impedance is either three times as large as Z_o or 1/3 as great. Since a voltage maximum appears at the end of the line it is obvious that the load impedance is greater than Z_o, in this case, three times Z_o.

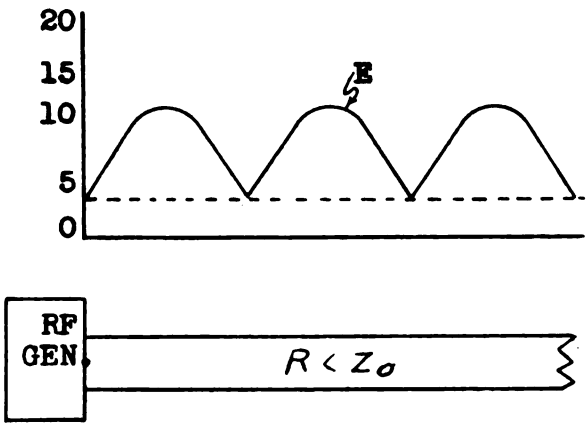

Fig. 7-11: Line Terminated in an Impedance Lower Than Z_o.

21. If the line is terminated in an impedance less than Z_o not all of the RF energy will be dissipated in the load some being reflected causing standing waves. Since the termination resembles a short circuit more than an open circuit a voltage minimum will appear at that point together with a current maximum. This indicates that the load resistance is less than Z_o, actually one third as great in Figure 11, since the standing wave ratio is indicated as three to one.

22. Thus far this discussion has dealt with lines terminated in a pure resistance, or open or short circuited. In such cases a voltage maximum appears at the load if its resistance is higher than Z_o and a voltage minimum if it is less than Z_o. If the line is terminated in a reactive load, either a capacitance or an inductance, the position of the standing waves shifts to a degree dependent on the reactance of the load. Consider a line terminated in a capacity.

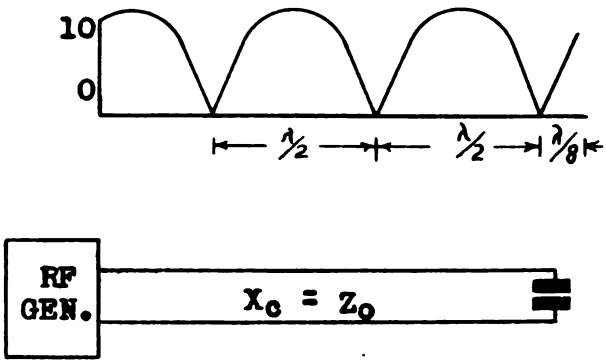

Fig. 7-12: Line Terminated in a Capacitive Reactance Equal to Z_o.

23. If the line is terminated in a capacitive reactance equal to Z_o a voltage minimum appears one eight wave length from the load. As the capacitive reactance is decreased the minimum moves away from the load allowing the voltage at that point to increase until finally with zero capacity a voltage maximum exists at that point, since the line is effectively open circuited.

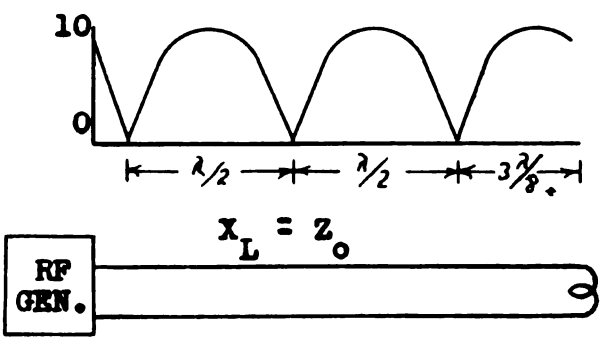

Fig. 7-13: Line Terminated in an Inductive Reactance Equal to Z_o.

24. If the line is termin-

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ated in an inductive reactance equal to Z_o, a minimum falls three eighths of a wavelength from the load. As the inductive reactance is decreased the voltage minimum moves toward the load until finally with zero inductance a voltage minimum exists at that point since the line is short circuited.

25. Impedance Along the Line: The impedance along the line is determined by the ratio of voltage to current at any given point and therefore varies continually from a high to a low value and back again. For example, at the shorted end of the line the current is maximum and the voltage minimum. The impedance therefore is low. One quarter wave back from the shorted, load end the voltage is maximum and the current minimum resulting in a high impedance. If the line losses are low and very little energy is dissipated in the load, the low impedance points are the equivalent of a short circuit. If the load resistance is made equal to Z_o standing waves no longer exist, the impedance along the line is uniform and equal to Z_o. A line so operated is called a "flat line".

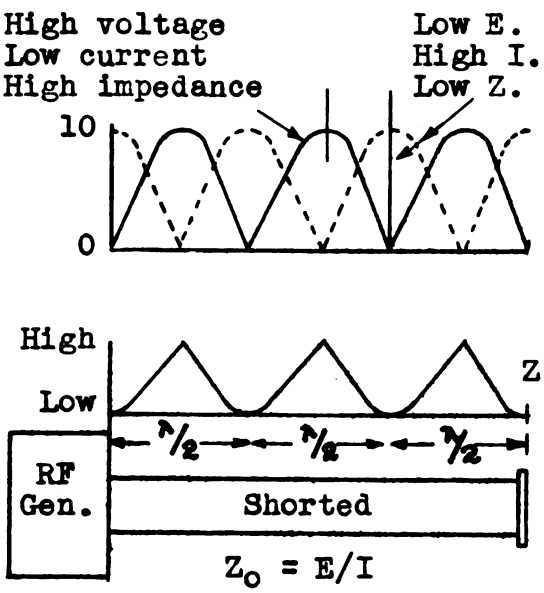

Fig. 7-14: Impedance Along a Line Terminated in a Short Circuit.

26. A line operated with a large standing wave ratio is called a "resonant line." Most transmission lines used in Radar are operated as flat lines as they may be cut to any reasonable length and offer a more efficient means of delivering power from one point to another. Resonant lines are critical as to length and tend to radiate considerable power from points of maximum voltage and maximum current and in addition are more susceptible to voltage breakdown. However, an unmatched or resonant line one or more quarter wavelengths long possesses some important properties of tuned circuits, transformers, and antennas, and are employed as such in various Radar equipments.

LINES AS TUNED CIRCUITS

27. The operation of sections of line as tuned circuits depends upon the existance of reflections and standing waves to produce the effect of high and low impedance. Therefore, sections of line so employed are either shorted or open at the end to produce maximum standing waves and the highest or lowest input impedance possible, as may be required by a given application.

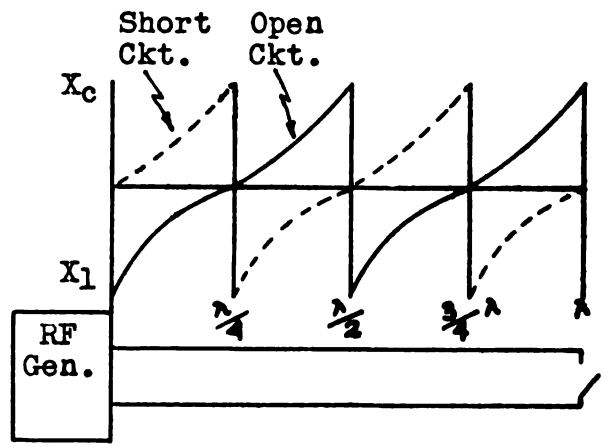

Fig. 7-15: Impedance Variation Along a Wavelength of Line When Open and Short Circuited.

28. Figure 15 represents

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the impedance along a section of line which is one wavelength long at some particular frequency. An examination of this chart will reveal the following properties of resonant sections of transmission line: (a) A section of line less than one quarter wave long and shorted at one end looks like an inductance at the other end.

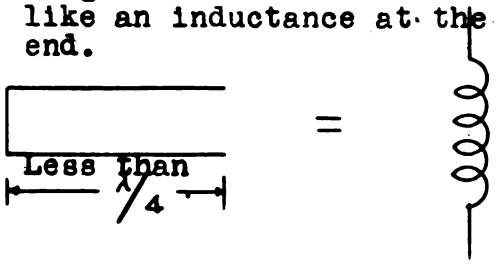


Fig.7-16.

(b) A section of line less than a quarter wave long and open at both ends looks like a capacity at either end.

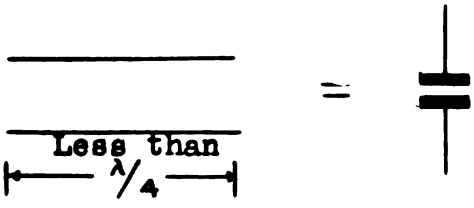


Fig. 7-17.

(c) A section of line longer than a quarter wave but less than a half wave and shorted on one end looks like a capacity at the other end.

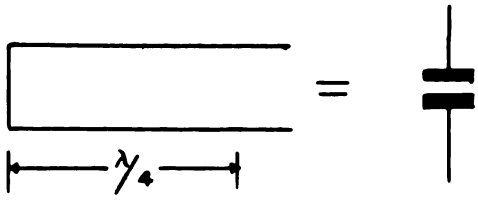


Fig. 7-18.

(d) A section of line longer than a quarter wave but less than a half wave and open at both ends looks like an inductance at either end.

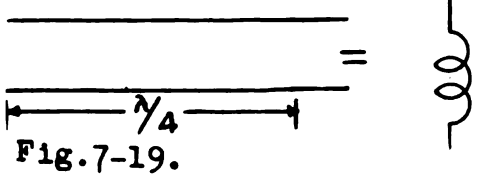


Fig.7-19.

(e) A section of line one eighth wave long and open circuited displays a capacitive reactance equal to Z_o. A section one eighth wave long and shorted on one end displays an inductive reactance equal to Z_o.

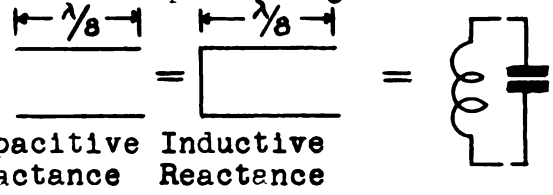
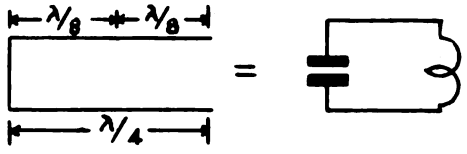


Fig.7-20

(f) If the two sections are connected together a shorted quarter wave section is obtained. This is the equivalent of a parallel tuned circuit. It,



Looks like a high resistive impedance or 'open circuit'.

Fig. 7-21.

therefore, displays a high resistive impedance or virtual open circuit at the open end. The voltage, current and impedance curves of a shorted quarter wave section are shown in Figure 22.

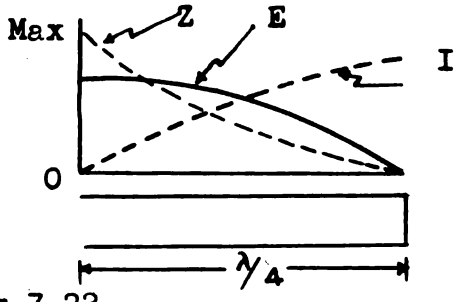


Fig.7-22.

(g) A quarter wave open section is the equivalent of a series tuned circuit therefore to an input applied to either end it presents a low resistance or virtually a short circuit. The voltage

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current and impedance curves of an open quarter wave section are shown in Figure 23. In this case it is assumed that the input is applied to the left end of the line.

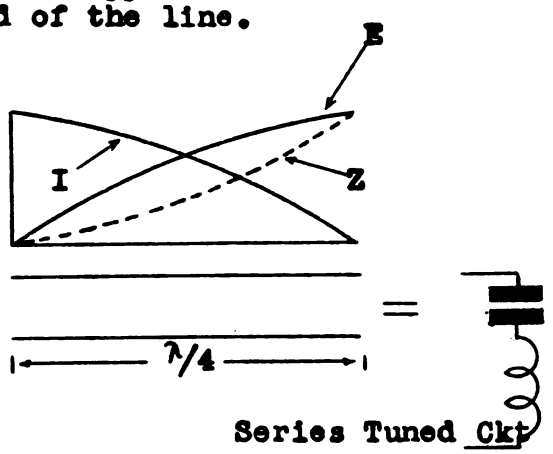

Fig.7-23.

(h) A half wave section of line shorted at one end displays a very low resistive impedance or short circuit at the other end. It is the equivalent of a series tuned circuit.

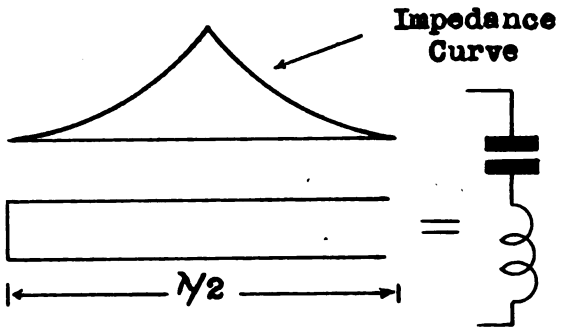

Fig.7-24.

(i) A half wave open section of line displays a high resistive impedance at either end. It is the equivalent of a parallel tuned circuit.

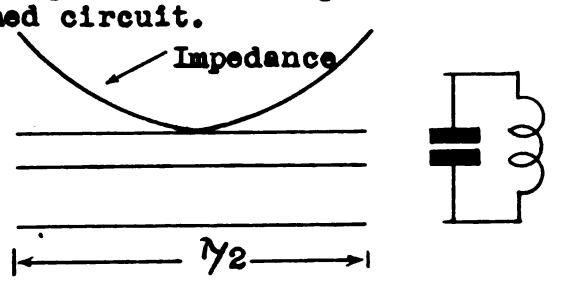

Fig.7-25.

29. From Figure 15 and the discussion which followed, the characteristics of lines as tuned circuits may be summarized as follows:

Quarter-wave, shorted and Half-wave, open	=	Parallel Tuned Circuit
Quarter-wave, open and Half-wave, shorted	=	Series Tuned Circuit

30. These conditions are encountered, not only in a single quarter-wave or halfwave length, but in longer lines as well since any given condition will be repeated at regular intervals along a line which is a number of wavelengths long. For example, any line an odd number of quarter-wave lengths exhibits the same characteristics as one quarter-wave, neglecting attenuation. In like manner, the characteristics of a half-wave (two quarter-waves) are exhibited by any line composed of an even number of quarter waves, or in other words, a line which is some number of half waves in length.

31. Examination of Figure 15 will show that a section of line, if made longer or shorter, is tuned above or below the input resonant frequency. This causes it to display inductive or capacitive reactance, rather than resistance just as in a conventional tuned circuit.

32. It has been pointed out that a resonant section of line could be employed as a tuned circuit, a transformer, or an antenna. The ability of a quarter wave section to act as an RF transformer or impedance matching device arises from the fact that it "inverts" the load as seen by the source. This inversion factor is traceable to the voltage and impedance variation along a quarter-wave as a result of the formation of standing waves. For example: a short circuit on one end of a

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quarter-wave section appears as an open circuit at the other end; an open circuit on one end appears as a short circuit at the other end; a low resistance on one end appears as a high resistance at the other; a high resistance on one end appears as a low resistance at the other. The input impedance in all of the above cases is equal to the line impedance squared divided by the load impedance.

$$\text{Input Impedance} = \frac{(Z_o)^2}{\text{Load Impedance}}$$

33. One of the most frequent applications is that of matching a flat transmission line to a different impedance load. Matching is necssary to effect an efficient transfer of energy from the line to the load and to prevent the standing wave ratio from becoming excessive (i.e. more than about 1.5 to 1 for a flat line) In this case it is desired to ascertain what impedance the matching section must display to effect the required transformation. The equation given above if solved for line impedance (Z_o of matching section) gives

$$Z_o \text{ of matching section} = \sqrt{(Z_o \text{ of line})\ (Z \text{ of load})}$$

34. For example: A 72 ohm antenna is to be matched to a 100 ohm transmission line. What must be the characteristic impedance of the quarter-wave matching section, to effect the required transformation? Substituting in the formula:

$$Z_o \text{ of matching section} = \sqrt{100 \times 72} = 85 \text{ ohms}$$

35. If an 85 ohm, quarter-wave matching section is employed the line looks into an impedance of

$$\frac{(Z_o \text{ of matching Sec.})^2}{Z \text{ of load}} = 72 \text{ ohms}$$

The antenna looks into a source of

$$\frac{(Z_o \text{ of matching Sec.})^2}{Z \text{ of line}} = 72 \text{ ohms}$$

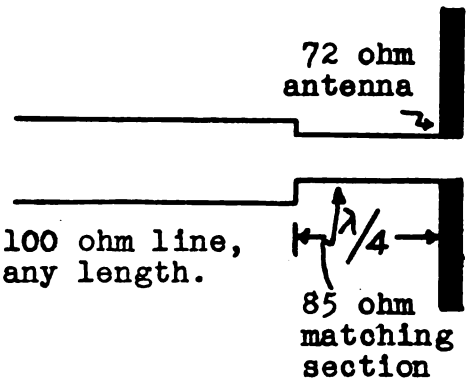

Fig. 7-26: Quarter Wave Section Used To Match 100 Ohm Line and 72 Ohm Antenna.

SECTIONS LESS THAN QUARTER WAVE

36. Sometimes it is desirable to know the impedance condition existing on one end of a section of line less than a quarter-wave long when the other end is terminated by various loads. These are summarized in the following statements.

(a) Section less than a quarter wave and terminated in a resistance equal to the line impedance at the other end looks like the line impedance.

(b) If terminated in an open circuit; looks like a capacitance.

(c) If terminated in a resistance higher than Z_o; looks like a capaditance with series resistance.

(d) If terminated in a short circuit; looks like an inductance.

(e) If terminated in a resistance less than Z_o; looks like an inductance with series resistance.

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LOAD INVERSIONS

37. The ability of a quarter wave section of line to "invert" the load as seen by the source was discussed under paragraph 32. Inversion of capacity and inductance can be effected by a section of line between a quarter and a half-wave in length. An open section of this length looks like an inductance to the source.

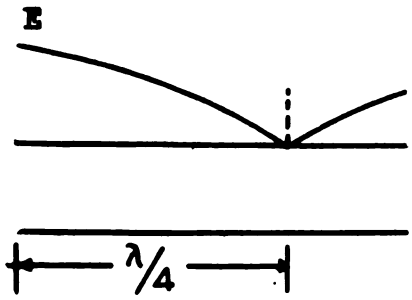

Fig. 7-27:

38. If a portion of the line less than a quarter-wave is cut off and replaced with an actual capacity the section still looks like an inductance to the source. This is true since an open section of line less than a quarter-wave is the equivalent of a capacity.

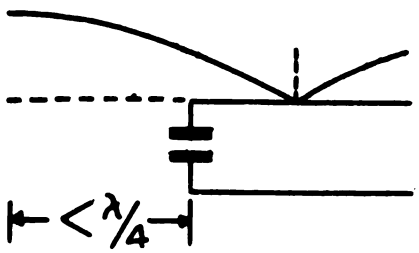

Fig. 7-28.

39. A shorted section of line between a quarter and a half-wave in length looks like a capacity to the source. If a section of the line less than a quarter wave (the equivalent of an inductance) is cut off and replaced with an actual inductance, the line still looks like a capacity to the source.

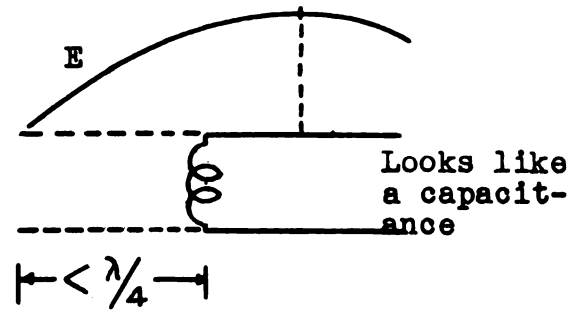

Fig. 7-29.

40. Some additional characteristics of a section of line between one-quarter and one-half wave in length are summarized below.

(a) Section of line between a quarter wave and a half wave and terminated in a resistance equal to Z_o; at the other end looks like Z_o.

(b) If terminated in an open circuit; looks like an inductance.

(c) If terminated in a resistance higher than Z_o; looks like an inductance with series resistance.

(d) If terminated in a short circuit; looks like a capacitance.

(e) If terminated in a resistance lower than Z_o; looks like a capacitance with series resistance.

41. If a single quarter wave section or any odd number of quarter waves acts as an inverter, it stands that a half wave (composed of two quarter waves) or any multiple of a half wave will act as a "double inverter" and therefore repeat whatever appears on the far end. As shown in Figure 30, an open circuit on one end appears as an open circuit on the far end. In

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like manner, a low resistance on one end looks like a low resistance at the other; a short circuit looks like a short circuit; a high resistance looks like a high resistance; a capacity looks like a capacity; an inductance looks like an inductance; a complex load looks like a complex load.

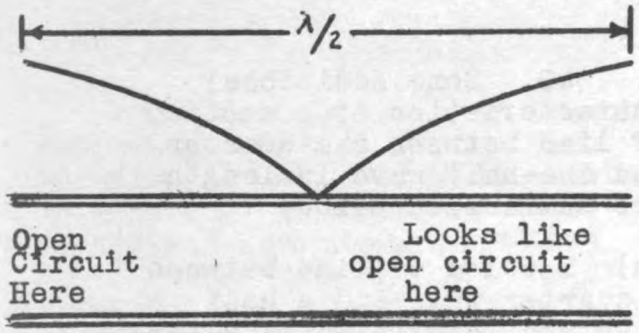

Fig. 7-30: Half Wave Line As A "Repeater".

APPLICATIONS

42. Slotted Line: A specially designed section of transmission line longer than a half wavelength and an RF voltmeter can be employed to measure the characteristics of other transmission lines and their loads. Such a device is commonly called a "Slotted Line". A block diagram of the equipment is shown in Figure 31. The slotted line as its name implies consists of an enlarged section of rigid coaxial line with a slot along the outer conductor to permit a movable RF probe to couple loosely to the inner conductor. The RF energy picked up by the probe is conveyed directly to a detector and voltmeter, all on the same sliding assembly. The complete detector unit consisting of probe, detector and voltmeter is sometimes referred to as a "traveling detector" -

43. If the line is supplied with RF energy of an appropriate frequency from some adjustable source, and a load connected to the end of the line, it is possible to slide the detector along the calibrated portion of the line and determine; (a) the standing wave ratio, (b) the position of these standing waves with respect to some "reference" point. From this data, and with the aid of specially prepared charts, it is possible to determine; (c) the resistive or reactive nature of a load at a given frequency, (d) to adjust an antenna for correct length or resonance, (e) to eliminate standing waves from a transmission line, (f) to determine the propagation or velocity constant of samples of transmission line. These are by no means all of its uses but they are probably the most outstanding.

44. Bazooka or Line Balance Converter: There are numerous instances in Radar equipments where it is necessary to change from a coaxial or unbalanced line (to ground) to a bal-

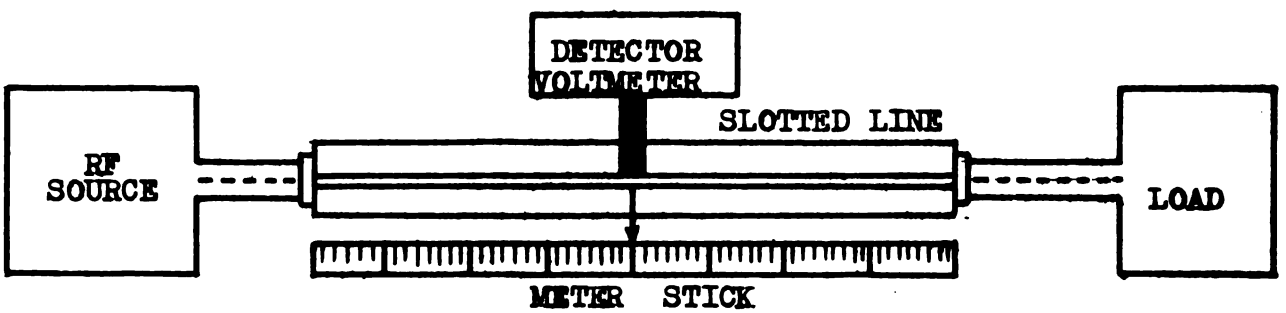

Fig. 7-31: Simplified Block of Slotted Line Equipment.

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anced line such as the shielded pair. Such a transition cannot be made directly since it represents a discontinuity in the line. This would result in an excessive standing wave ratio and the loss of considerable energy by radiation due to unbalanced line currents. To effect such a changeover it is customary to use a "Bazooka" or line balance converter, sometimes called a phase inverter. It will be recalled that the outer skin of the outside conductor of a coaxial line is at RF ground whereas the outer skin of the inner conductor is well above ground potential; and therefore displays a comparatively high impedance to ground. Both conductors of the balanced line, however, display the same potential and the same impedance to ground under ideal conditions.

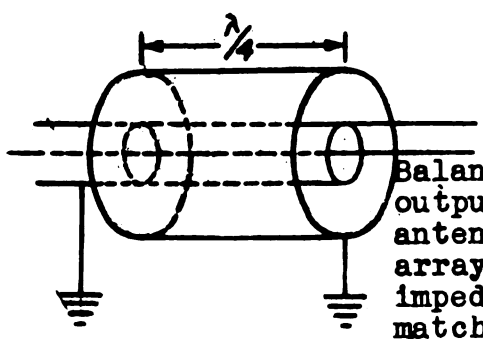

Fig. 7-32: Bazooka or Line Balance Converter.

45. The object of the bazooka is to make the shield of the concentric line have a high impedance to ground where it connects to one side of the balanced line and thus convert to a balanced condition. This is done by placing a quarter-wave shield around the end of the coaxial line. This auxiliary shield is connected to the shield of the coaxial line a quarter-wave from the end of the line as shown in Figure 32. The outer shield is bonded firmly to ground or the surrounding structure. Thus these two shields form a quarter wave section shorted at one end. Earlier in this chapter it was pointed out that the input end, of a shorted quarter-wave displays a high impedance. Thus where the balanced line is attached to the coaxial structure, it is connected to two points, both of which have a balanced high impedance to ground. The inner conductor was already at a high impedance and the action of the shorted, quarter-wave raises the end of the outside conductor of the coaxial line to a correspondingly high impedance.

46. Tuning Out Load Reactance: A transmission line is normally terminated in a resistive load. In practice however, there is usually some amount of residual capacity or inductance present at the load in addition to resistance. To prevent standing waves this reactive component must be "tuned" out. This can be accomplished by connecting enough capacity or inductance across the load to form a parallel-tuned circuit with its reactance at the operating frequency. A parallel tuned circuit presents a very high resistive impedance.

47. The same effect can be attained somewhat more efficiently at high frequencies by connecting an additional section of transmission line of such a length that it presents inductive or capacitive reactance, as may be required, across the load. For example, assume that a 90 ohm line is terminated in a 90 ohm resistance which displays some capacitive reactance at the resonant frequency. A shorted section of line, or stub, less than a quarter-wave is connected across the load and the variable short moved until the amount of inductive reactance offered by the stub resonates with the capacitive reactance of the load. This can be checked accurately with a slotted line.

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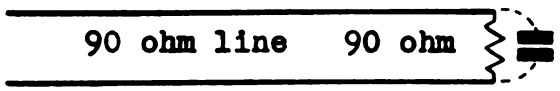
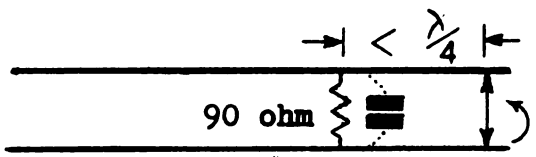
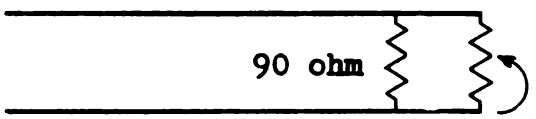
The transmission line then looks into a 90 ohm load shunted by a much higher resistance. While an ordinary resistance is used in this illustration, for the sake of clarity, the same conditions would apply to a useful load such as an antenna.



(A) Line terminated in load that displays some capacity.



Variable short -
(B) Inductive Stub added.



High resistive impedance of tuned circuit

(C) Line now looks into 90 ohms shunted by a high R.

Fig. 7-33: Tuning Out Load Reactance.

48. Transmission Lines As Tuned Circuits: At the ordinary ultra high frequencies resonant sections of transmission line are used as tuned circuits instead of the conventional lumped capacity and inductance. This is necessary since it is difficult at such frequencies to construct an inductance in the ordinary manner and yet keep the capacitive reactance high between the adjacent coil turns. If the capacitive reactance is low only a small amount of inductance can be used to bring the circuit to resonance. Under these conditions the impedance of the circuit will be low and little voltage can be developed across it. Another factor is that there is less RF skin resistance in a transmission line or linear type of tank circuit than in one employing lumped constants. In general a linear tank circuit is more efficient than a conventional tuned circuit, that is it has a higher Q, since it loses less energy in the ohmic, hysteresis, eddy current, dielectric, or radiation forms.

49. A pair of lines a quarter-wave long, shorted at one end, can be substituted for a coil - condenser tank circuit. The total length of the lines through the shorting bar will then represent one-half-wave, so the circuit will oscillate with the voltage across the open ends 180 degrees out of phase, which is the effect produced by a coil and condenser combination tank circuit. Figure 34, illustrates transmission lines as tuned circuits, both open pair and coaxial.

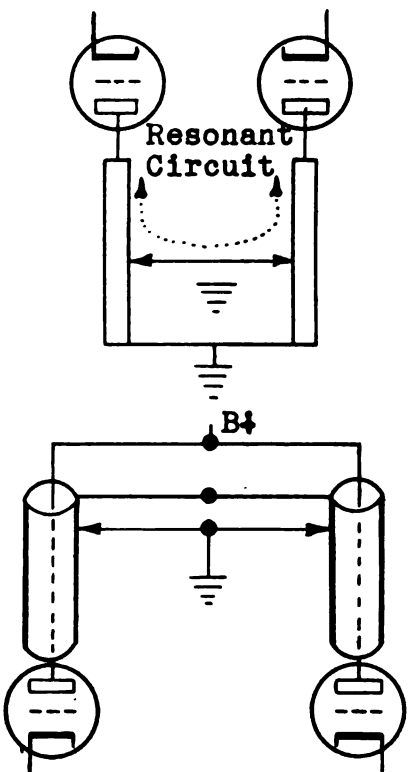


Fig. 7-34: Transmission Lines Employed As Tuned Circuits.

50. Shorted Quarter Wave Section as an Insulator: A section of line a quarter-wave

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long at the operating frequency and shorted on one end may be used as an insulator, since it presents a very high impedance at the input end.

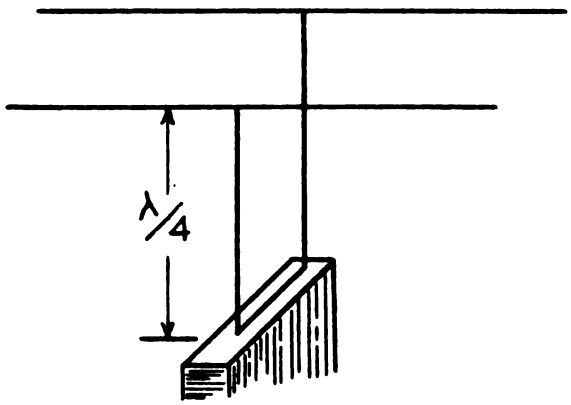

Fig. 7-35: Shorted Quarter Wave As An Insulator.

51. Shorted Quarter Wave Section As a Transformer: A shorted quarter wave, either coaxial or open line, may be used as a step-up transformer in a manner similar to a parallel tuned auto transformer. A shorted quarter-wave either coaxial or open-line, may be used as a step-down transformer.

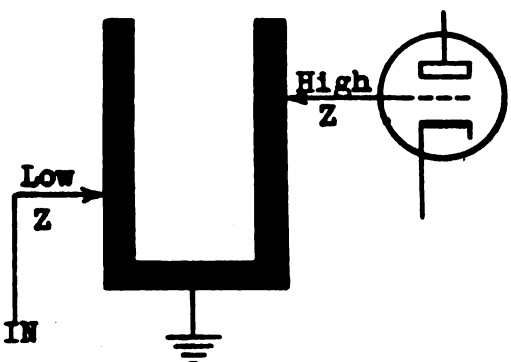

Fig.7-36: Shorted Quarter-Wave as Step-Up Transformer.

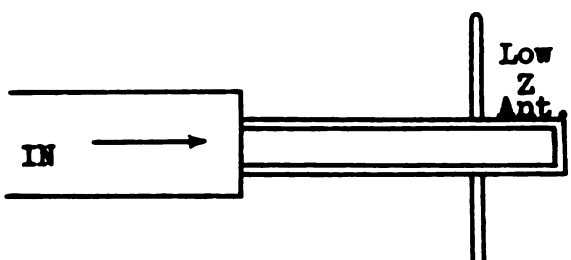

Fig.7-37: Shorted Quarter-Wave As Step-Down Transformer.

52. Use of Resonant Sections in Switching Circuits: In many Radar equipments the problem illustrated by Figure 38 is encountered. It is necessary at certain times to prevent signals entering the system at A from reaching B. This is effected by closing the switch on the end of the half wave section. This shorted condition is reflected to point X. Since the quarter-wave section is now shorted on the end near B it presents a high impedance to the transmission line thus preventing any appreciable energy from reaching B. This is the principle of Radar duplexers and is discussed in detail in Chapter VIII.

WAVE GUIDES

53. At the highest frequencies used in Radar today another more efficient type of transmission becomes possible. Here the radio frequency energy from the transmitter is 'piped' to the antenna through a hollow metal tube called a "wave guide". A wave guide is ideal for this purpose since it introduces much less loss than any other means and is of the simplest possible construction. It is not used at lower frequencies because its size is dependent upon wave-length and becomes too large to be practical at even the lower micro-waves.

54. It is not convenient to think of the action of a wave guide in terms of current and voltage, but rather in terms of the electrostatic and electromagnetic fields involved. These fields are always present when electrical energy is transmitted but are usually thought of only when dealing with radiation. A comparison with sound waves may be helpful. When someone speaks, the sound waves produced normally

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travel outward in all directions in a manner similar to the radio waves leaving an antenna. But if the person were to direct his voice into a speaking tube, the sound energy would be confined to the inside of the tube and could be sent a considerable distance without appreciable loss.

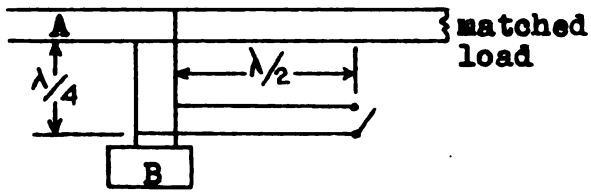

Fig. 7-38: Resonant Section As Switching Circuit.

55. Most wave guides are rectangular in shape. Their dimensions are not extremely critical but must meet certain requirements. Reference to Figure 39 shows that one of the dimensions of the guide must be greater than a half wavelength.

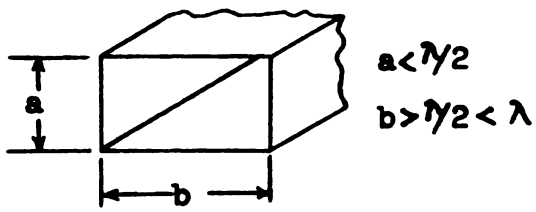

Fig. 7-39: A Rectangular Wave Guide.

If this condition is not met, i.e., if the guide is too small for the frequency being used, energy will not pass through it. The thickness "a" is not critical but must not be too small because of the possibility of voltage breakdown.

56. Wave guides have a characteristic impedance depending on the dimensions of the guide, which must be matched to prevent standing waves and reflections. At the radiating end, a fair match is obtained by simply utilizing the open end of the guide, but a better match results if the end is flaired slightly. In other words an actual antenna is not needed. The RF energy will be radiated from the end of the guide.

57. In practice, a parabolic reflector is added to increase directivity. A crystal detector is used in the reception of signals. By proper placement in a resonant chamber the crystal may be made to absorb practically all of the energy sent to it through the wave guide.

58. Stubs may be used with wave guides for the same purposes as with transmission lines, but there are important differences. The characteristics of resonant sections of a wave guide are shown in Figure 40.

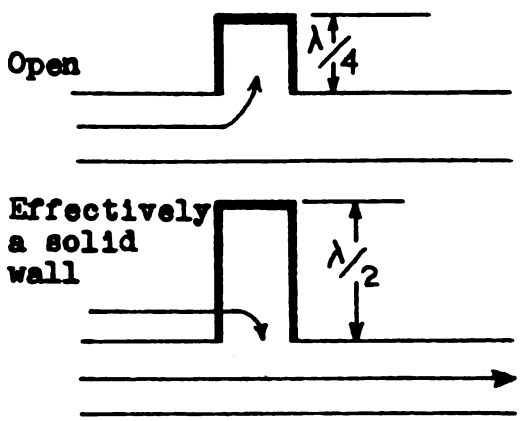

Fig. 7-40: Resonant Sections of Wave Guide.

Important points to be remembered are: (a) A quarter wave, or odd number of quarter waves, shorted at the end reflects an open circuit where it is attached to another guide. (b) A half wave, or multiples of a half wave, shorted reflects a short where it is attached to another guide. In other words there is effectively no opening present and no energy will be allowed to enter the half wave section.

59. One form of wave guide does not use a metal pipe to confine and direct the RF energy

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It uses, instead, a solid rod of insulating material such as polystyrene. The action is similar to that which takes place when light is conducted through a lucite rod.

ANTENNAS

60. In developing a simple half-wave antenna it may be helpful to consider it first in the form of a quarter wave section of open pair line as in (A) of Figure 41. Throughout the discussion on transmission lines it was emphasized that the spacing between the two conductors must be a small fraction of a wave length to allow the opposing electromagnetic field to "buck out" and prevent radiation. The purpose is to convey as much of the energy as possible from the RF source or transmitter to the antenna since the latter is designed to radiate the energy more efficiently and with the required directional characteristics. Inasmuch as the line is terminated in an open circuit the standing wave ratio is maximum causing a short circuit to exist at point "x".

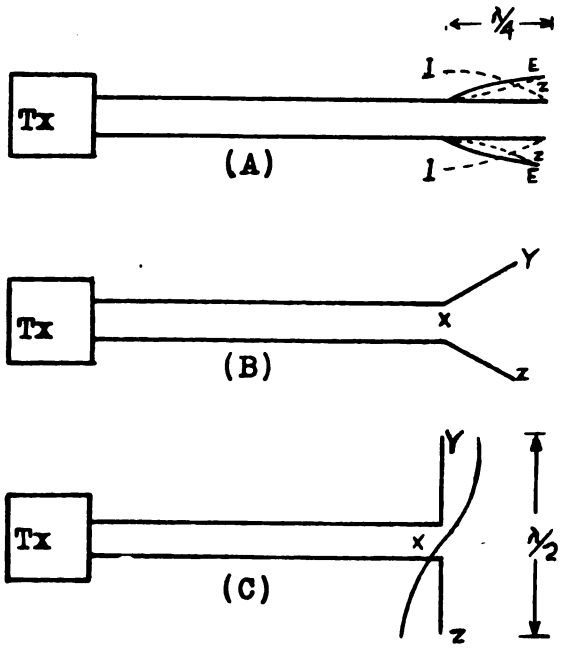

Fig.7-41: Development of Dipole.

61. Now consider the changes taking place if the quarter-wave section on the end of the line is bent outward as in (B). Since the two conductors are no longer closely spaced at the end of the line considerable radiation takes place. This means that the energy is not all being reflected back into the line as in (A), therefore points "y" and "z" in (B) are no longer the equivalent of an open circuit. The standing wave ratio along the line is thereby reduced causing the impedance at point "x" to rise from zero to some higher value.

62. In (C), of Figure 41, the quarter-wave section is bent fully perpendicular to the major portion of the line resulting in maximum radiation since cancellation of the electromagnetic field between the two halves is now minimum. The quarter-wave section of (A) is now a half-wave radiating element or antenna, commonly called a dipole. The dipole, or half-wave element, is the fundamental radiator from which most of the other types are developed. In free space it presents an impedance at its center of 72 ohms. The impedance at point "x" of (C) may be assumed to be approximately 72 ohms. This then is the terminating impedance of the line. Assuming a 100 ohm line, the impedance mismatch in this case is 100 to 72, giving a standing wave ratio of approximately 1.4 to 1.

63. Thus far it has been assumed that the dipole is an electrical half-wave. Physically it is slightly less than a half wave long because of the "end effects" due to the small capacity that exists between the ends and ground. Compared to the ordinary LC oscillatory circuit, this has the effect of adding a small amount of capacity to the condenser. To compensate for this, i.e., to tune to the desired frequency, the antenna

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must be slightly shorter than would be indicated. If the antenna is too short it reflects some capacitive reactance back into the line. If too long it reflects inductive reactance. In either case the position of the standing waves along the line is shifted giving an indication of the amount and sign of the reactance. A slotted line is quite useful in measuring the reactance and indicating when it is tuned out.

64. Radiation Resistance: The energy radiated from an antenna may be accounted for by assuming it to be equivalent to the loss encountered if the antenna current were flowing through a fictitious resistance, termed the "radiation resistance". This loss is separate and distinct from any other losses that may exist and is the only useful loss in the antenna system. It may be defined:

Radiation resistance =

$$\frac{\text{total power radiated}}{(\text{antenna current})^2}$$

Since the radiation resistance of an antenna is measured at a current maximum, and since there is a current maximum at the center of the dipole just discussed, the impedance and radiation resistance at that point may be considered the same. It must be remembered however, that the impedance rises to a much higher value at either end of the dipole.

65. Voltage Feeding: RF energy may be fed to an antenna at a point of high voltage. For example in Figure 42 a 90 ohm two wire line is to be coupled to a dipole at a high voltage point. To avoid the severe mismatch that would occur with a direct connection the impedance transformation property of a shorted quarter wave stub is employed. The 90 ohm line is connected to various points along the stub until the 90 ohm point is found, preferably with the aid of a slotted line. Since the open end of the stub is a high voltage, high impedance point it may be connected directly to the end of the antenna.

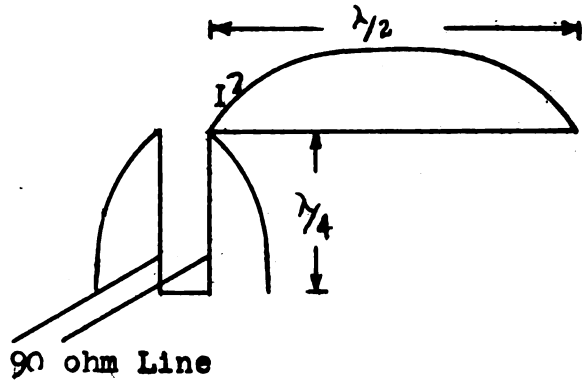

Fig. 7-42: Voltage Fed Dipole.

61. Current Feeding: RF energy may be fed to an antenna at a point of high current. For example in Figure 43 a line of 200 ohms impedance is to be coupled to a dipole at the point of high current in the center. A shorted half-wave stub is required here. The transmission line is connected to the stub at a 200 ohm point.

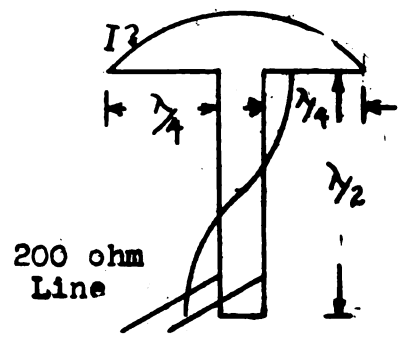

Fig. 7-43: Current Fed Dipole.

67. Parasitic Antennas: The simple dipole antenna tends to radiate energy almost equally well in all directions. Such a characteristic is not suited to Radar applications where it is desired to concentrate all of

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the energy on a small sector to obtain maximum reflections. To obtain unidirectional characteristics an antenna array consisting of a simple half-wave radiating, or driven, element with a system of parasitically excited elements is employed. A typical parasitic, or Yagi, array is shown in Figure 44. Only the driven element is connected to the transmission line. The other elements are parasitically excited in that they pickup energy from the radiating element and re-radiate it with such a phase relation with respect to the driven element that radiation is reinforced in the forward direction through a rather narrow arc, thus wasting very little energy in other sectors. The reflector, to act as such, should be about 5% longer than the driven element. The directors, usually one to four in number should be somewhat shorter than the driven element. The length of the parasitic elements and their spacing with respect to each other and the driven element is adjusted to obtain the desired directivity, or lobe pattern.

68. An analogy sometimes helpful in picturing the action of such an array is to compare it with an automobile headlamp assembly. The reflector in the array may be thought of as the reflector in the headlamp. The driven element corresponds to the light globe placed at the focal point of the parabolic reflector. The director or directors correspond to the lens system in the headlamp.

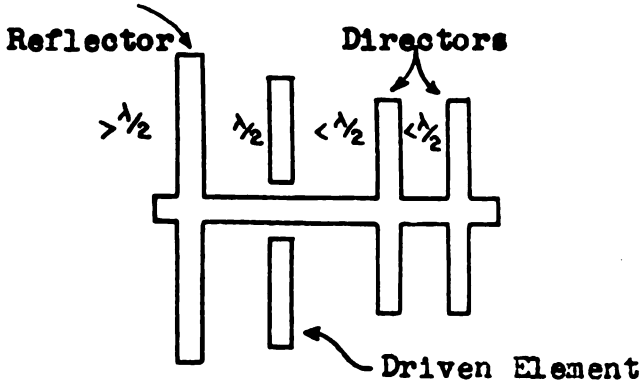

Fig. 7-44: Parasitic or Yagi Array.

69. Colinear Array: Another array sometimes used at the ordinary ultra high frequencies is the Colinear array. It consists of a string of half wave antennas in phase. The in-phase relation is necessary to produce maximum radiation in a plane perpendicular to the axis of the array. The elements would be out of phase with each other if connected end to end. Therefore it is necessary to insert quarter wave phasing stubs between each element producing a 180 degree delay to effect the in-phase relation. Off the ends of the array the radiation is considerable reduced.

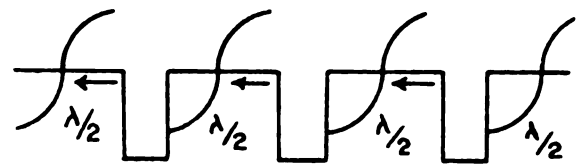

Fig. 7-45: Colinear Array.

70. Micro Wave Antennas: The micro waves border on the heat and light wavelengths and possess many of their characteristics. Like heat or light these waves can be directed by a parabolic reflector. Figure 46 illustrates a typical airborne, micro wave antenna.

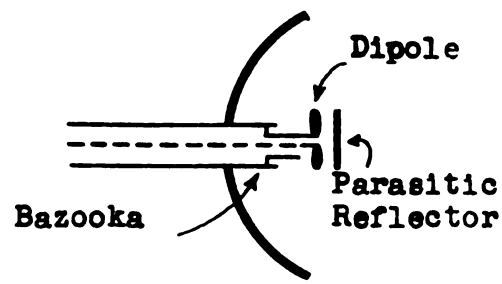

Fig. 7-46: Micro Wave Antenna.

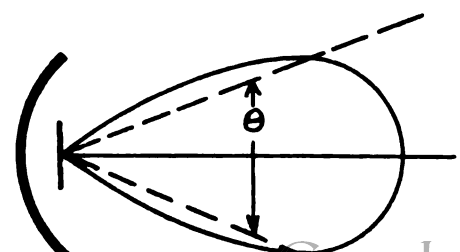

Fig. 7-47: Lobe of a Parabolic Microwave Antenna.

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71. The dish, or parabola, is large in comparison with the wavelength used. RF energy is fed to a dipole placed at the focal point of the parabola by means of coaxial line or waveguide. About one quarter-wave out from the dipole is placed a parasitic reflector such as may be found in the ordinary parasitic array, to allow no energy to be radiated directly out from the dipole. Most of the radiation is reflected back into the parabolic reflector and then out as a beam of electromagnetic energy. In general, the larger the parabolic reflector, the narrower is the radiated beam.

72. Most Radar systems use the same antenna for transmitting and receiving in conjunction with some form of duplexing equipment. This can be done since the properties of an antenna apply both to receiving and transmitting. Thus the more efficient an antenna is for transmitting the better it is for receiving. If a directive antenna system displays a certain field pattern in one direction on transmitting, it will display that same field pattern on receiving. Likewise the voltage and impedance variation all along the antenna will be the same on either operation.

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CHAPTER VIII

Receiver Protector Systems

THE ANTENNA SWITCH

1. Radar in its simplest form would require two antennas, one for the transmitter and another for the receiver. Such a system has several inherent disadvantages. The receiving antenna would have to be thoroughly isolated from the transmitting antenna to prevent the high power of the transmitted pulse from feeding directly from the transmitting antenna back into the receiver and so damaging the input stage of the receiver. Even if the input stage were not permanently damaged, it would be overloaded to such an extent that the receiver would be blocked for several hundred micro-seconds or more; thus the receiver would be inoperative and would not amplify a pulse return from a nearby object. Aside from this defect, it is readily apparent that one receiving antenna would not permit satisfactory determinations of directional data.

2. An improved system, then, would utilize a bi-directional transmitting antenna and two receiving antennas. One receiving antenna would be directional to port and the other to starboard. Thus the transmitted energy would be sent simultaneously to port and starboard. If an object were to starboard, the reflection would be received on the starboard receiving antenna; similarly, for an object portside. This would require two receivers, connected as shown in Figure 1, to enable the operator to ascertain whether the signal was reflected from an object to port or starboard. With this arrangement, an object to port would reflect energy into the port receiving antenna; this would be amplified and detected in receiver "A" and fed to the indicator CRT causing a deflection of the beam to the left, indicating an object portside.

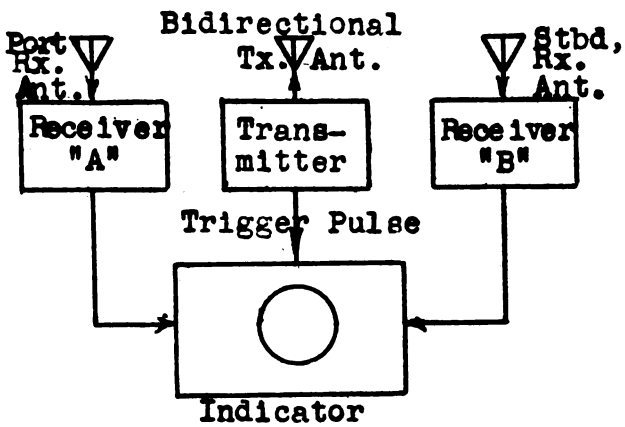

Fig.8-1: A Two Receiver Radar System.

3. There is a rather obvious disadvantage to the above system. The two receivers required mean extra weight, extra space, extra cost, and greater

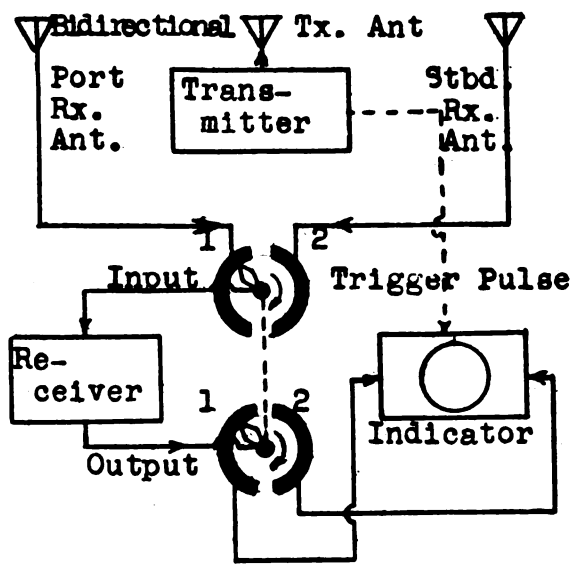

Fig.8-2: A Functional Diagram of an Antenna Switch

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maintenance. These are all important items in design considerations. To overcome this disadvantage a double-pole-double-throw switch, commonly known as an antenna switch, is used. When connected as shown in Figure 2, only one receiver is required. With the switch in position "1" the port antenna is connected to the input of the receiver, and the output of the receiver is connected for deflection to the left on the face of the CRT. If the switch is in position "2", the starboard antenna is in use and any return would cause a deflection to the right on the face of the scope.

4. This switching should be accomplished at a rate rapid enough that, to the eye, the indicator would appear to show simultaneously the blips from both port and starboard. The human eye can detect changes up to a rate of approximately 16 per second; therefore, if the switch is motor driven at a rate of about 30 cps or 1800 rpm, then no effects of the switching will be visible. Notice in this regard that, since the transmitter is normally pulsed about 400 times per second, approximately 6 pulses will be sent out and reflected back on the antenna while the switch is making a single contact.

5. Figure 3 illustrates the timing of the switch. Several considerations are of importance here and so determine the actual time relationships shown. The 5° gap in the antenna switch is to assure that both antennas will not be connected at any instant. Notice also that at the time the input to the receiver is being switched from port antenna to starboard antenna, or vice versa, the output of the receiver is not connected to the indicator. This is to prevent the switching from appearing as noise on the face of the scope.

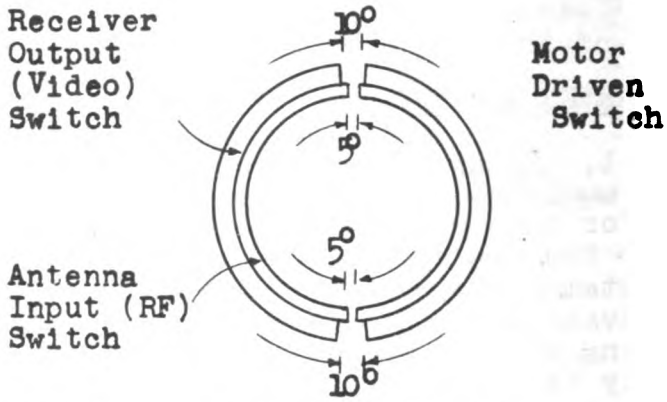

Fig.8-3: An Antenna Switch Timing Diagram.

DUPLEXER

6. As set forth above, there are two receiving antennas, and a separate transmitting antenna that radiates simultaneously to port and starboard. Since an antenna exhibits similar directional characteristics when receiving and when transmitting, if it could be arranged to transmit on the two receiving antennas, a number of advantages could be derived. First, the weight, cost, and wind resistance of the separate transmitting antenna would be eliminated. Second, in the system previously discussed returning echoes were received alternately from port and starboard, yet the system was transmitting simultaneously to both sides, thereby wasting an unnecessarily large portion of the transmitted power by sending it in a direction from which echoes could not be received. Using the receiving antennas alternately for transmitting would mean that the energy would be sent out on the antenna in use at that instant, and so energy would be radiated only in the direction being received.

7. The chief obstacle involved in use of the same antenna for transmitting and receiving is

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the necessity for some means of protecting the receiver input circuits when the transmitter pulses. It is also necessary to prevent the weak received signal from being wholly or partially lost by following the transmission line back to the transmitter. A device designed to overcome these obstacles must be capable of "switching" for time intervals as small as a few microseconds, since the receiver must be effective immediately following the transmitted pulse. This microsecond timing means that the device must be electronic and not mechanical. Such a device is shown in Figure 4 and is known as a DUPLEXER OR REPROD (REceiver PROtective Device). The location of this DUPLEXER in a typical radar system is shown in Figure 5.

8. The duplexer is constructed of coaxial transmission line with certain critical lengths (see Figure 4). It functions on the principle of quarter wave impedance transformation. The operation can best be shown by following a pulse of energy from the transmitter. When the transmitter pulses, the energy is inductively coupled into the pickup loop at point A, Figure 4, and follows the transmission line to point B. At point B, looking toward the antenna, an impedance match is seen, due to the fact that the antenna is adjusted to match the impedance of the coaxial line. Energy from point B also tends to reach point C, where an impedance step-up occurs in the resonant quarter-wave section DE.

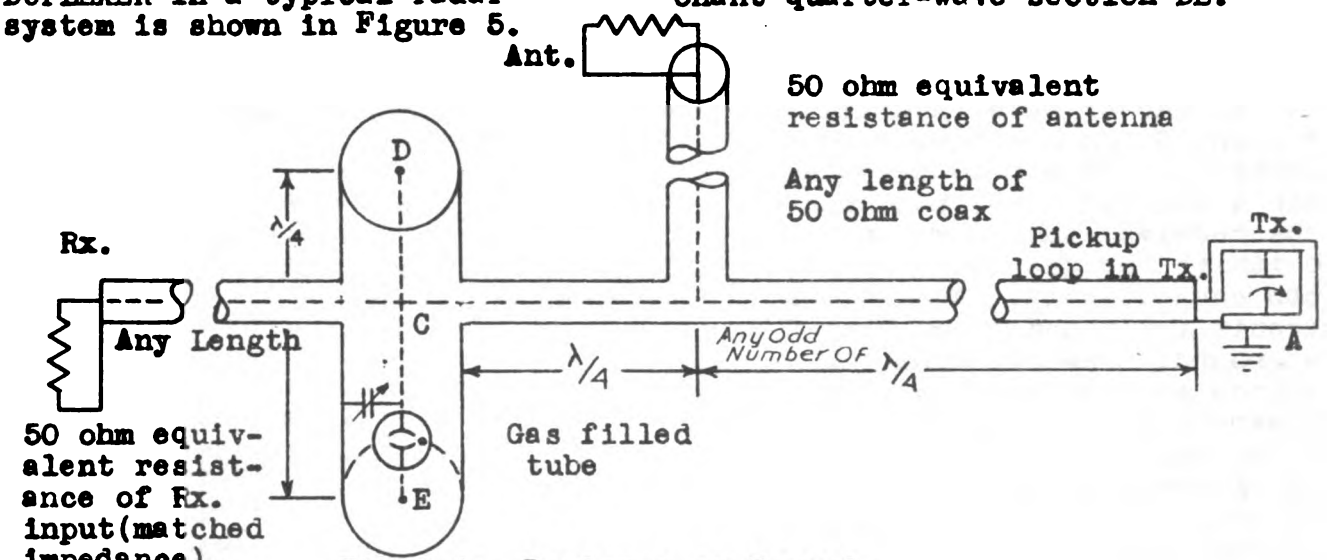

Fig.8-4: Duplexer or Reprod.

Compare Figure 5 with Figure 2 (which is the system required if the duplexer is not used).

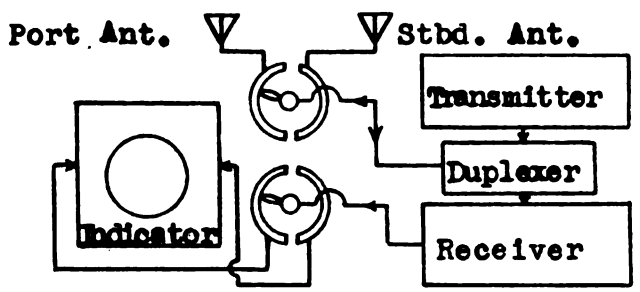

Fig.8-5: A Duplexer - Antenna Switch System.

Since this quarter wave is shorted at point D, then a very high impedance will exist across the gas tube at point E; thus a voltage will be developed across it, causing it to ionize and conduct. This places an effective short circuit at point E. With the quarter wave thus shorted at both ends (points D and E), a very low impedance is present at point C. This reflects a high impedance one quarter wave back to point B, looking at C. Therefore energy

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reaching point B will follow the impedance match to the antenna, rather than attempt to reach the receiver.

9. As soon as the transmitter pulse ends, there is no longer any high voltage to keep the gas tube ionized, so it again assumes an "open circuit" or non-conducting state. Assume that the pulse meanwhile has been reflected, received by the antenna, and has returned to point B. Since the distance from the grounded point A to point B has been adjusted to be an odd number of quarter waves, then at point B looking toward point A, a high impedance exists and so prevents the received signal from being dissipated in the transmitter loop.

10. The returned pulse reaches point C. From C to D there is a section of line less than a quarter wave, shorted at point D, thus acting inductively. From C to E is less than a quarter wave, but open (the received pulse is too weak to ionize the gas tube) and so acts capacitively. A parallel circuit is formed from point C to ground, presenting an impedance much higher than that presented by the input circuit of the receiver. As a result the received signal follows the impedance match existing in the receiver input. Therefore the duplexer is performing the important function of allowing the returned signal to reach the receiver, but preventing the high power of the transmitted pulse from reaching the receiver and blocking or damaging it.

POLYPLEXER

11. It has been shown that if the same antenna is to be used for both transmitting and receiving, a duplexer is required. If the direction of a received signal is to be known, an antenna switch is required. Therefore, in a typical meter search setup these two functions may be performed by a unit known as the POLYPLEXER or ANTENNA SWITCHING UNIT. This unit consists of both the electronic switch or duplexer and the motor driven antenna switch. The duplexer section is exactly the same as that previously discussed. Some change must be made in the antenna switch from the type previously mentioned, however, since the system no longer utilizes a separate transmitting antenna. It requires a switch capable of handling the high power of the transmitted pulse, in addition to the weak returned signal. Since no metallic switch would be capable of handling this high power at the speed involved, an antenna switch has been developed that functions on the principle of quarter-wave transformation.

12. Figure 6 shows a polyplexer containing the regular duplexer and the modified type of antenna switch.

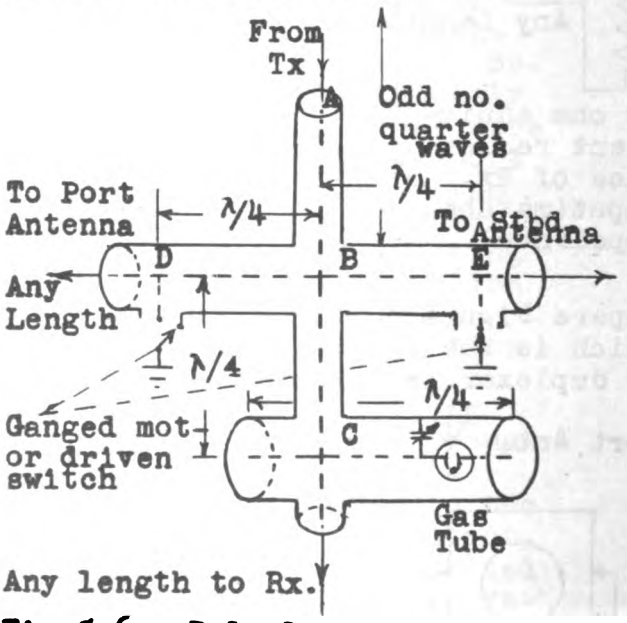

Fig.8-6: Polyplexer.

Its operation is as follows: The motor driven switch is <u>alternately</u> shorting point D

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and point E to ground. This is accomplished with timing similar to that of Figure 3. Note that the switch points are each located exactly one quarterwave from point B. The transmission line leading out to the antennas can be any length, but the distance from B to D and B to E is critical. With the coax shorted at point D a high impedance is reflected to point B (looking at D) preventing the transmitted pulse from going out the port antenna. When point D is shorted, point E is open, reflecting a low impelance at B looking at E, therefore the pulse can follow down the transmission line to the matched impedance presented by the starboard antenna. Remember that the gas tube in the duplexer fires when the transmitter pulses, and so protects the receiver. If a target exists to starboard, energy will be reflected back into the starboard antenna. Switch point E will still be open (the transmitter pulses and echoes may be received approximately seven times before the antenna switch changes position) and so the received blip will reach point B. Here a high impedance exists looking toward points A and D. However, the gas tube of the duplexer is no longer ionized; therefore the blip follows through point C to the receiver, since a matched condition exists along this path.

13. The transmitter again pulses, and the procedure is repeated about six or seven times; then the antenna switch shorts point D. It now can be seen that further pulses of the transmitter will be sent to port and echoes received from port in a manner similar to that described for the starboard direction. Note that at the instant the switch motor shorts the starboard antenna, the video section of the switch must connect the receiver output to the port deflection plate of the indicator.

14. An improvement over the unit shown in Figure 6 was made by adding a half wave section of line at point D and another at point E giving a system as shown in Figure 7. The advantage of this is purely mechanical.

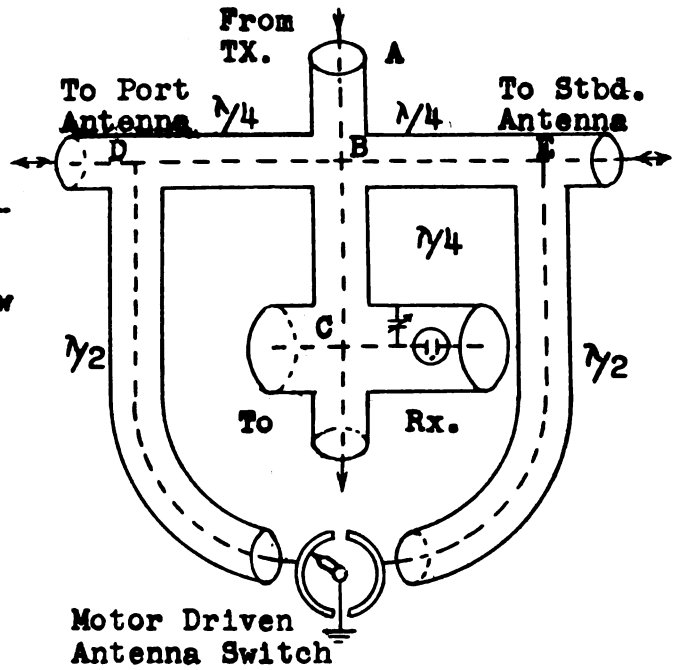

Fig.8-7: An Antenna Switch Unit.

It avoids the necessity of a mechanical shaft to rotate the switches at the remote points D and E, by allowing the switches to be mounted directly at the motor and using the half wave lengths of line to reflect shorts back to points D and E.

T-R BOX

15. With the development of Radar at the micro wavelengths the older directive systems of port and starboard antennas was replaced by a single, but rotatable, antenna of the parabolic reflector type. This eliminated any need for an antenna switch; however, some type of duplexer was still required since this same antenna would be used for both transmitting and receiving, i.e., the receiver still needs protection.

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16. At the microwave frequencies, ordinary receiving tubes are impractical for the mixer stage of a receiver, due to the effect of their shunt capacities. Therefore, microwave receivers ordinarily use a crystal as a first detector. Under these circumstances, duplexers of the type discussed have several disadvantages. In the ordinary duplexer using the gas tube, a considerable voltage is required to cause the gas to ionize. This means that an instantaneous peak of voltage will reach the receiver before the gas tube fires. This peak, while not too damaging to an ordinary tube, is sufficient to burn out any crystal such as used for the input stage in microwave equipment. Thus a type of duplexer had to be developed that would have more instantaneous action, i.e., one that would fire at a lower voltage.

17. With the development of microwave gear came a desire to decrease the minimum range over which the equipment would be effective. This was of great importance in fire control apparatus. One of the factors limiting the minimum range attainable is the recovery time of the tube used in the reprod. Recovery time is defined as the period necessary for the circuit to return to a point of half-normal sensitivity. This time is approximately 3 microseconds in a circuit using the ordinary gas tube in the reprod, which would mean three microseconds from the time the transmitter pulsed until a returned signal would be effective in the receiver. Since the receiver itself requires over one microsecond recovery time, it is important to keep the recovery time of the reprod tube under that figure.

18. To overcome the two previously mentioned disadvantages, there was developed for the microwave equipment a type of duplexer known as the T-R BOX; meaning "Transmit-Receive" Box. In other words, this is just another name for a duplexer or reprod.

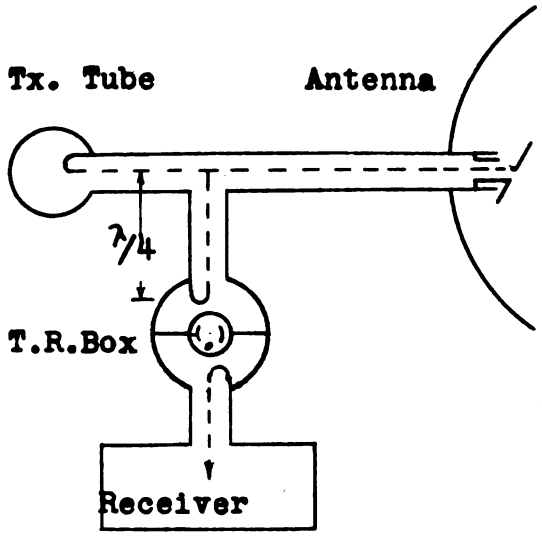

Fig.8-8: T-R BOX - INTERCONNECTION.

This T-R box functions in a manner similar to that used in meter search gear; i.e., its purpose is to short a point in the coaxial line leading to the receiver, and by so doing reflect a high impedance back to its junction with the coax leading from the transmitter to the antenna (See Figure 8).

19. Figure 9(A) shows a functional cut-away view of this type of T-R box, while Figure 9(B) is the electrical equivalent circuit. Note that Figure 9(A) shows a high potential (commonly known as "keep-alive" voltage) applied to one electrode of the vapor-tube. This voltage holds the gap nearer the breakdown point, so that a smaller potential will be required for ionization, and so cuts off the receiver more rapidly, preventing the crystal or other input circuit of the receiver from being burned out during the initial rise of voltage as the transmitter fires

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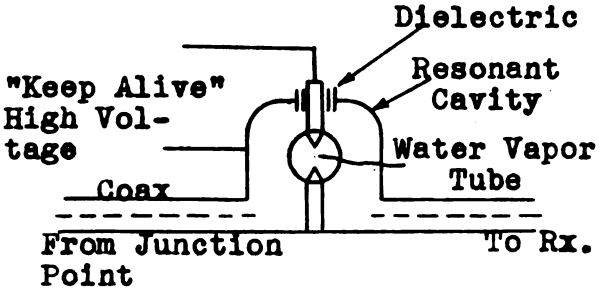
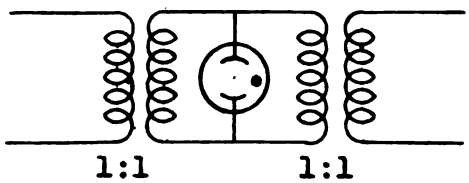
20. The cavity of the T-R box is resonant at the transmitter frequency, acting as a parallel resonant circuit as shown in Figure 9(B).



A: Functional



Parallel Resonant--Q-400

B: Electrical Equivalent

Fig.8-9: T-R BOX

Therefore, when the transmitter pulses, a high potential develops across the spark gap which breaks down, thus detuning the resonant circuit and thereby preventing further transfer of energy to the coaxial line leading to the receiver. The tuned circuit (i.e., the resonant cavity) has a Q of approximately 400; the impedance across this cavity is, therefore, very high when the spark gap is not firing and so will have no adverse effect when a weak signal is received.

21. A water-vapor tube is shown in Figure 9(A). Use of this type of tube cuts down the recovery time so that it is within the limits previously outlined. Figure 10 gives a comparison of the recovery time of the water-vapor tube as compared to the meter-search type of gas-filled tube; note that the recovery time is less than .5 microsecond for the water-vapor tube.

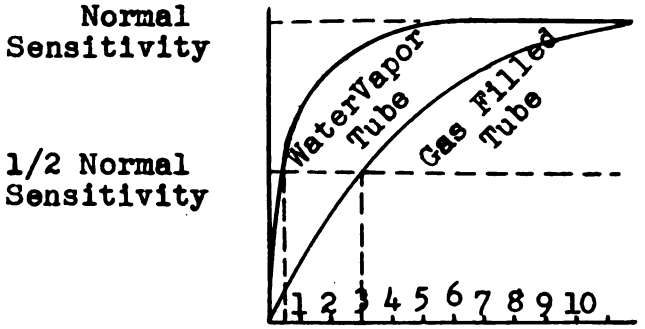


Fig.8-10: Recovery Time of T-R Boxes.

22. The graph of Figure 11 brings out another point of interest. It is plotted as the amount of signal reaching the receiver when the water-vapor tube is firing, against time or age of the tube. The water-vapor tube used on a T-R box has a life of better than 1000 hours, as shown.

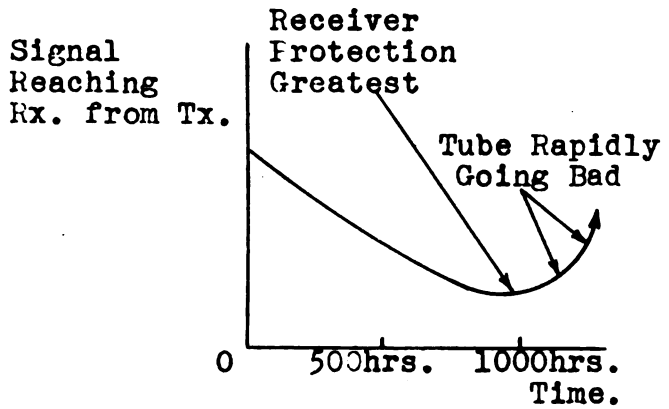


Fig.8-11: Performance Curve of a Water-Vapor T-R Box.

A study of the graph indicates that the performance of the tube increases with age until it reaches a point where it suddenly starts to go bad; this is evidenced by the rapid rise in the amount of transmitted energy reaching the receiver or crystal. This shows that, if left in too long, the tube will function so poorly that sufficient voltage will reach the

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crystal to burn it out.

23. With equipment developed for the higher microwave frequencies, a single rotatable antenna was again used, so here again the requirements could be met by a T-R box. However, since waveguide is being used in present types instead of coaxial transmission line, the position of the T-R box has to be different. In a waveguide, energy flows along the inside walls on the pipe; if there is an opening in the side of the waveguide, e.g., the receiver junction, no energy will flow past that point. If a short can be reflected to the opening in the wall, the energy will move down the waveguide as though the wall were solid. Therefore, the T-R box must be one half wavelength from the point of junction as shown in Figure 12.

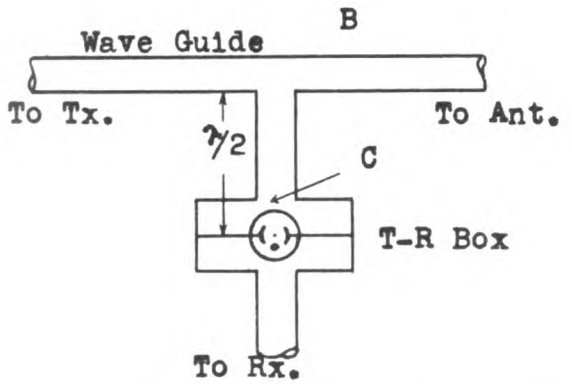

Fig.8-12: T-R Box in a Wave-Guide.

When the transmitter pulses, the water-vapor tube in the T-R box fires, and a short is reflected one half wave back to point B, effectively sealing the wall of the wave guide--thereby protecting the receiver and allowing the transmitted energy to flow out the waveguide to the antenna. When receiving, the water-vapor tube does not fire, so the returned pulse is able to follow down the wave-guide, past the T-R box to the receiver.

ANTI T-R BOX

24. The type of transmitter tube used at microwave frequencies has a fairly constant impedance when conducting or "hot", that is in the vicinity of 50 ohms at each of the several microwave frequencies. This 50-ohm value provides a good impedance match, to either the 50-ohm coax line or the waveguide. However, when "cold", or not firing, the transmitter tube presents to the waveguide or transmission line an impedance that is primarily a function of the "Q" of its resonant cavaties. This "Q" decreases at extremely high frequencies in a manner similar to that in which the "Q" of an ordinary tuned circuit decreases. As a result, the cold impedance of the transmitter tube used at the higher microwave frequencies is in the vicinity of only 500 ohms as compared with 5000 ohms for the lower microwave frequencies.

25. At these lower frequencies this 5000 to 50 (100 to 1) mismatch with the transmission line is sufficient to prevent appreciable loss of energy in the transmitter tube, from a reflecting object. At the higher microwave frequencies, it is seen that the mismatch may be in the vicinity of 10 to 1, which is not sufficiently bad to prevent losing much of the received energy in the transmitter tube. As a result, it is necessary to modify the system, shown in Figure 12, by the addition of another box, called the ANTI-T-R BOX, giving an arrangement as shown in Figure 13. This anti-T-R box is identical to the T-R box except as to purpose. The anti-T-R box prevents the received pulse from following the waveguide back to the transmitter tube. Referring to Figure 13 it is seen that, when the transmitter

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pulses, the water-vapor tubes in both the T-R and anti-T-R boxes fire, sealing the wall of the waveguide at points A and B, leaving the transmitted energy only the direct path to the antenna.

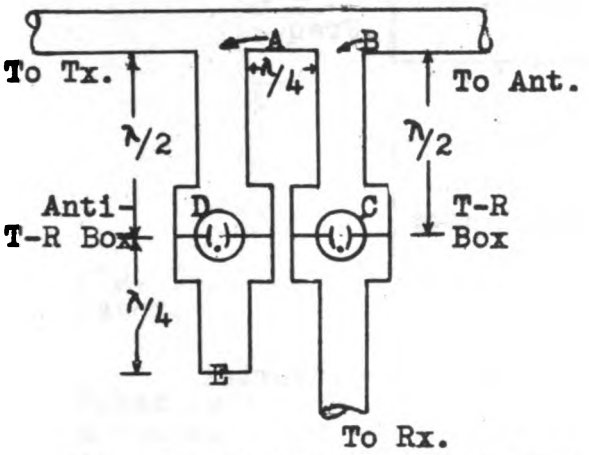

Fig. 8-13: Waveguide System.

26. When receiving, the tubes are not fired. It is now three/quarters of a wave length from the shorted end of the anti-T-R box to the wall of the waveguide at point A. This reflects a high impedance to point A, effectively leaving the wall of the waveguide open at this point and so preventing the received signal from passing in the direction of the transmitter tube. Thus the received signal sees a low impedance path only in the direction of the receiver.

RESONANT SLITS

27. Developmental work shows that a slotted metal plate such as is shown in Figure 14 will, when placed in a wave guide, act as a band pass filter, passing only the frequency to which it is resonant (as determined by its dimensions). If a pulse of high power, such as the transmitted pulse, appears across the slit it will cause a voltage breakdown and create a short across the waveguide at that point.

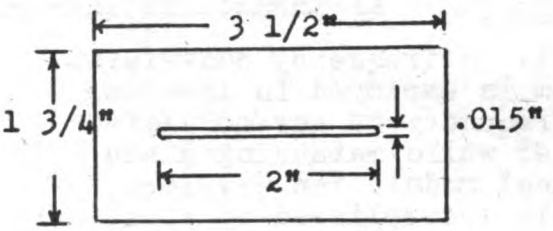

Fig. 8-14: Resonant Slit.

If this slit is sealed in a vacuum and placed in the waveguide system (refer to Figure 15), it can be used as either a T-R or an anti-T-R box.

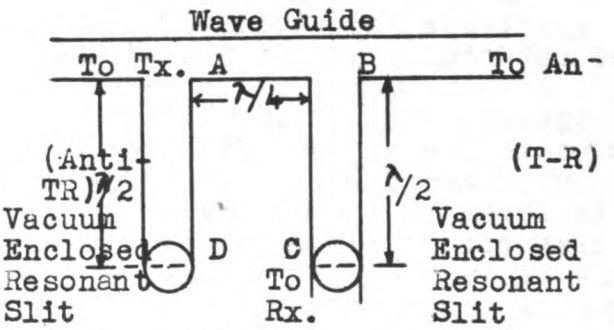

Fig. 8-15: Resonant Slits as Either T-R or Anti-T-R Boxes.

When the transmitter pulses, these slits arc over and reflect a short back to points A and B, just as in the case of the ordinary T-R and anti-T-R boxes. When a weak signal is received, it passes point C to the receiver, due to the band pass characteristic of the slit. The slit at point D also acts as a high impedance at the received frequency and so prevent much of the received energy from passing point A and reaching the transmitter.

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CHAPTER IX

Frequency Conversion Systems

1. A frequency conversion system is employed in lowering the frequency of any modulated carrier while maintaining the original modulation envelope. This is accomplished by "beating" the received signal in a mixing circuit with the output of a local oscillator and selecting the difference frequency.

2. To state briefly the need for a converter, it may be said that such a system is desired when the original frequency is too high to be amplified conveniently with existing tubes. That is, if the frequency under consideration is so high that the interelectrode capacities of the tubes materially affect the signal, or if, for instance, it is so high that transit time of the electron flow in the tubes becomes significant, then the use of a system to lower the frequency without disturbing the modulated component is required. The beat frequency produced when the original and the local signal are mixed is called the intermediate frequency and is usually abbreviated as IF.

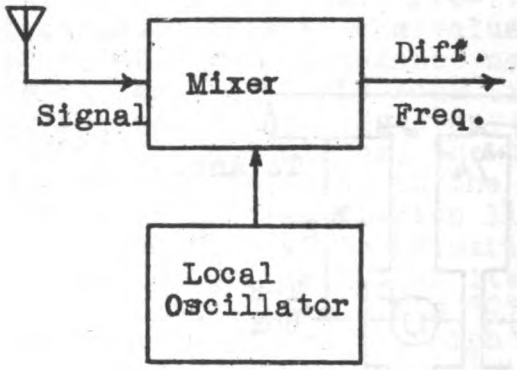

Fig. 9-1: A Simple Converter System.

LOCAL OSCILLATORS

3. In Figure 1, the simplest form of a converter system is shown. The frequency received on the antenna is fed directly to the mixer, which in most cases is a tube, and the output of the oscillator is also fed to the mixer. The local oscillator must always remain at the correct difference frequency with respect to the incoming signal, which in Radar would be the echo of the transmitted pulse, in order to produce the correct beat frequency or IF.

4. Conventional Types: In meter type Radar equipment, the local oscillator is of more or less conventional design, such as is found in short-wave receivers. That is, it embodies no radically new principles in its design. The circuit constants may be of better quality than ordinarily used in short wave receivers, with high Q inductances, but the principle of operation remains the same.. Two types of oscillators used in conversion systems of this particular frequency catagory are the Ultra Audion and Colpitts. In Figures 2 and 3 the conventional Ultra Audion and Colpitts oscillators, respectively, are shown.

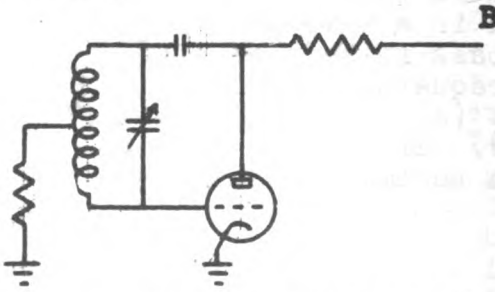

Fig. 9-2: The Ultra Audion Oscillator.

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5. The circuit constants may vary from the usual inductances and capacities necessary to produce a high impedance at a certain frequency to the use of open wire, or Lecher lines, and coaxial lines as resonant circuits.

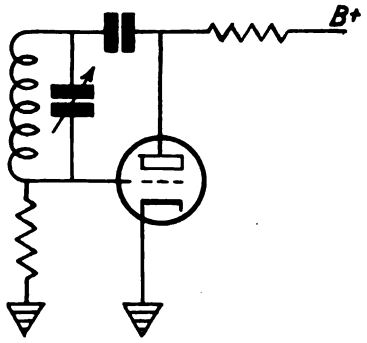

Fig. 9-3: The Colpitts Oscillator.

These latter methods of obtaining a resonant circuit are used when it is not practical, because of the high frequency, to use lumped inductances and capacities. For instance, the oscillator in Figure 1 could be redrawn showing shorted quarter wave lines used as the resonant circuit. In Figure 4, the Ultra Audion is shown with shorted lines acting as a resonant circuit in its grid-plate circuit and a half wave coaxial line to keep the cathode at ground potential.

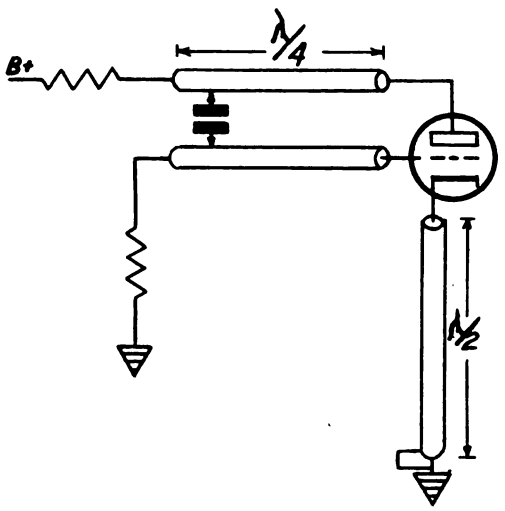

Fig. 9-4: Ultra Audion Oscillator Utilizing Shorted Quarter Wave Lines.

6. It is possible to vary the resonant frequency of the tuned circuit by varying the length of the lines. Another principle which is used is that of the shorted turn. By placing near the plate and grid lines a shorted loop or turn and varying the distance between the two-the inductances of the lines can be varied. As the proximity of the shorted turn and the lines is increased the inductance decreases, raising the resonant frequency of the circuit.

7. Microwave Local Oscillators: In this particular portion of the frequency spectrum the local oscillators depart considerable from conventional design. Under this division fall such types as reflex klystrons and "Lighthouse Tubes". Their operation, however, is as easy to comprehend as that of the conventional type.

8. The Reflex Klystron: The reflex klystron is a device for converting DC energy into RF energy by alternately slowing down and speeding up an electron beam, utilizing the transit time between two points to produce an alternating current which delivers power to a cavity resonator. A cavity resonator as in Figure 5 is a form of resonant circuit in which the current is distributed on the inner surface of an enclosed chamber. By making the chamber of proper dimensions, the circuit can be made to have a very high Q at microwave lengths. An electron gun, similar to those in cathode ray tubes, furnishes a beam of electrons with a uniform average velocity which flows coaxially through the tube. Perpendicular to the beam axis is a pair of grids. The grids are connected to the cavity resonator as shown in Figure 6. The electrons have a velocity, v_0 (due to the acceleration of the DC resonator voltage), which is considered as the mean velocity of the electrons.

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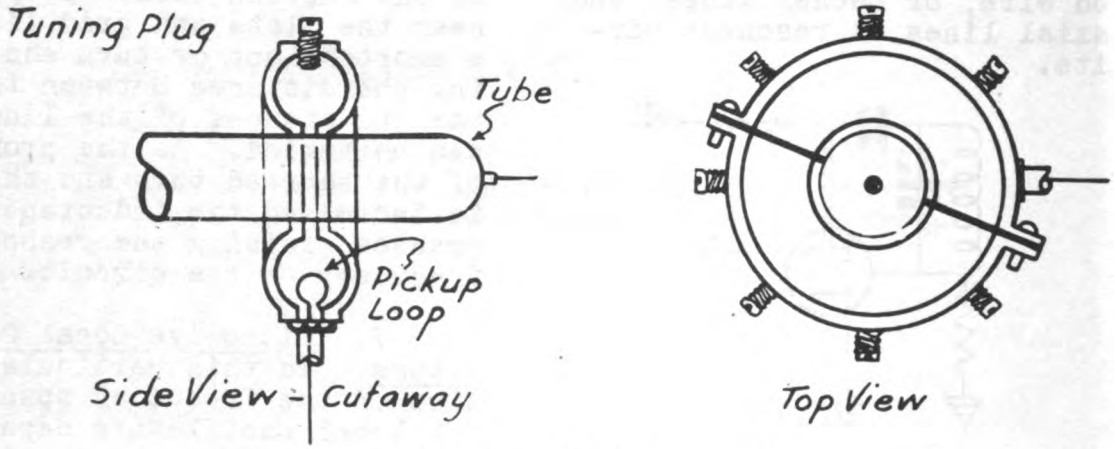

FIG. 9-5: Cavity Resonator

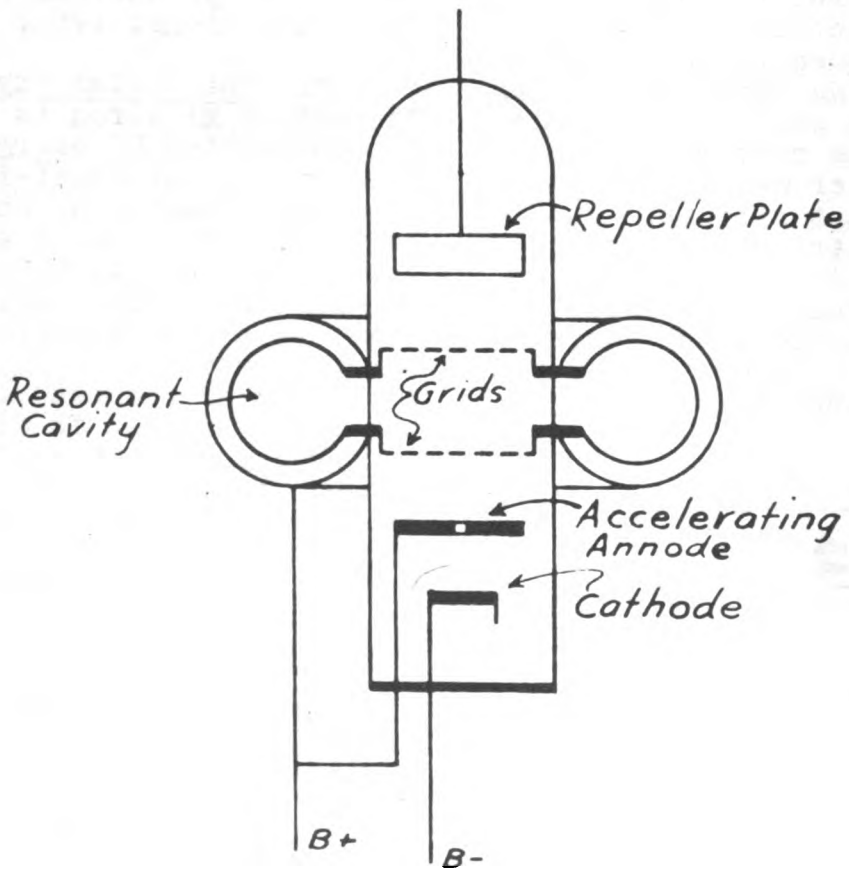

FIG 9-6: The Reflex Klystron

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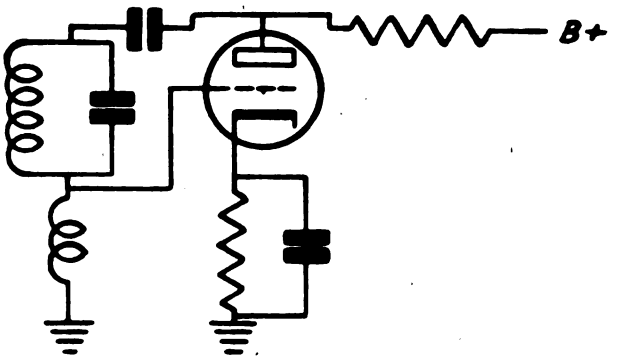

FIG. 9-7: Equivalent Crkt. Of The Lighthouse Oscillator

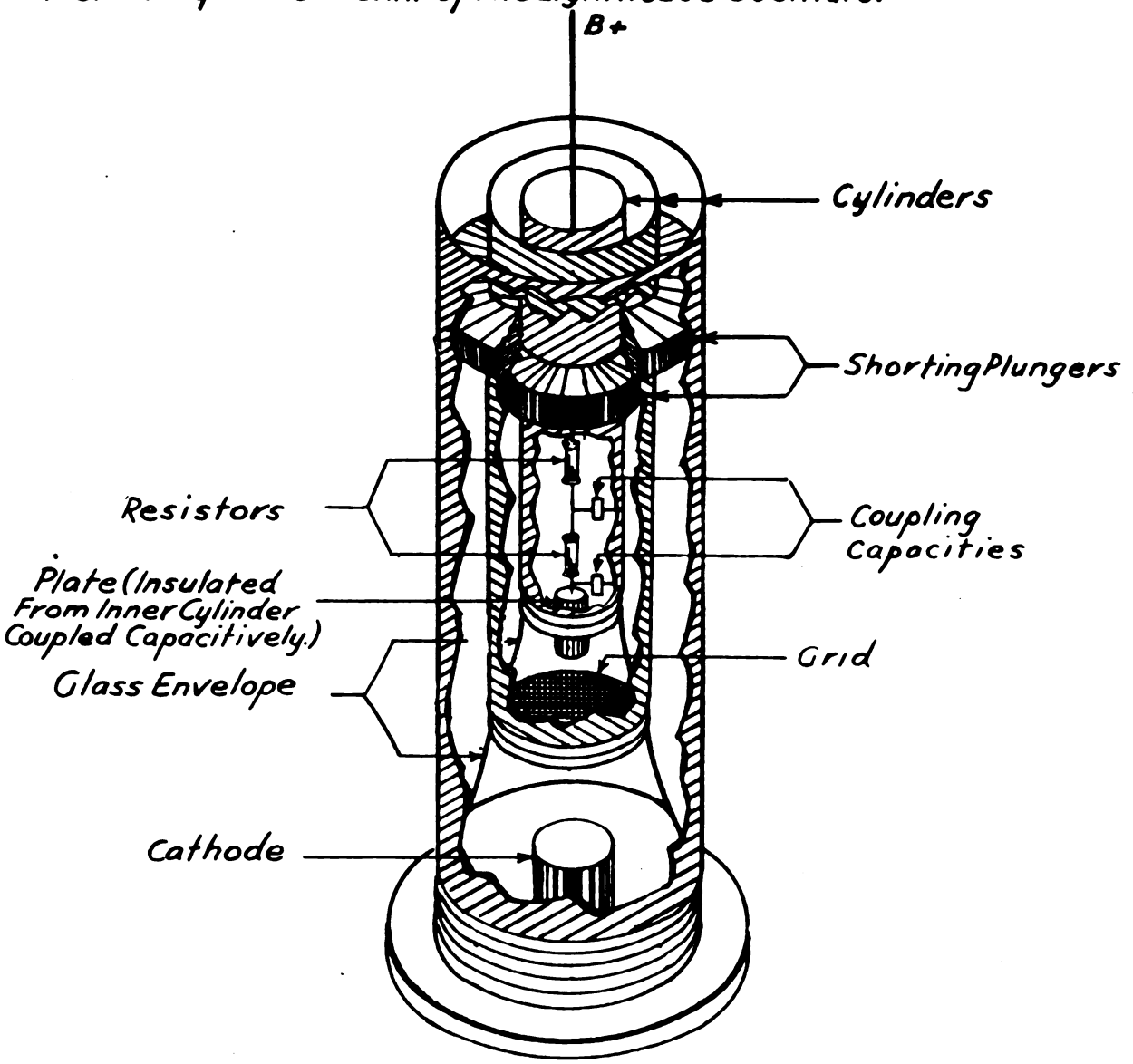

FIG. 9-8: Lighthouse Oscillator

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9. Assume that the cavity is oscillating. There will be an electrostatic field between the two grids, alternating sinusoidally, at the resonant frequency of the cavity. This field will accelerate, retard, or have no effect on electrons passing through the grid structure, depending upon the phase of the electric field when the electrons pass through the grids.

10. The electrons which pass through the grids while this field is zero, will maintain their original velocity, V_o. After they pass through the second grid they continue toward a repelling or reflecting plate which is usually operated with a negative potential applied to it. In traveling toward the repeller plate, the electrons which have been accelerated by the field between the grids will tend to catch up with those whose velocities remain unchanged, and the electrons which have been decelerated will fall back to the v_o electrons. While the electrons are in this space, owing to their unequal velocities a "bunching" effect occurs. The higher velocity electrons penetrate this retarding field more and approach the reflector more closely than do the lower velocity ones, and therefore the high velocity electrons actually travel farther for a given repeller voltage.

11. The bunched electrons are ultimately forced back to the grids of the cavity with such a phase relationship that oscillations are maintained. This eliminates the necessity for double cavities, as in ordinary klystrons, simplifying the tuning problems and eliminating some of the drift space that would be required between two cavity resonators, since the same function is accomplished by the reflex principle in much less distance. There is one complication in the reflex klystron, however. The repeller electrode voltage is very critical. This usually requires that its power supply be very well regulated.

12. For a constant resonator voltage, a range of repeller voltages may be found through which oscillations occur. This range is known as the repeller voltage mode and several such voltage modes may be found by varying the repeller voltage from minimum to maximum.

13. There is one repeller voltage in each voltage mode which yields maximum power output. The frequency at this point may be varied slightly when the repeller voltage is varied, so that a vernier control of oscillator frequency is available. This makes possible the use of an automatic frequency system wherein it is only necessary to vary the DC voltage on the repeller in order to make the correct change in frequency. (See Chapter 19)

14. The determining factor in the frequency of the klystron is the cavity resonator. In some reflex klystrons the cavity is tuned by variable plugs in the cavity. The plugs when inserted further into the cavity act as shorted turns, decreasing the inductance. In other types of klystrons the spacing between the grids is changed by mechanically warping the cavity. In all cases the cavity is the important frequency determination element. The output to be fed to the mixer is taken out of the klystron by a loop inserted into the cavity.

15. The Lighthouse Triode: The Lighthouse triode, so called because of its similarity in appearance to a lighthouse, is another local oscillator for use in the microwave region. Its equivalent circuit is shown in Figure 7 and is similar to an Ultra Audion type oscillator. The construction of a Lighthouse

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tube is shown in Figure 8. The tube base and glass envelope are so designed that they can be screwed into the cylinders which form the resonant circuits in the same fashion that an ordinary incandescent lamp is inserted in its socket. Tuning is accomplished by adjusting the shorting plungers between the cylinders. This is similar to tuning Lecher or parallel lines by moving a short along its length.

MIXERS

16. Several methods of combining the input signal and the local oscillator signal to produce the intermediate frequency can be used. Most prominent among these are diode, grid, grounded grid triode, and crystal mixing circuits. In all cases the purpose of the mixer is to separate the beat caused by the two signals and isolate it from those frequencies so that it alone may be amplified further in the following stages. For this reason the mixer is often called the first detector.

17. Diode Mixers: Since the combined wave is always applied to a detecting circuit, so that the desired beat frequency is contained in its output, use is often made of a diode. In principle its operation is identical to that of reproducing the modulated components of a radio frequency wave from a broadcast transmitter. In this case it contains in its plate circuit or cathode circuit, depending on the arrangement used, many components, some of which will have frequencies that are the sum and the difference of the frequencies of the various sine waves introduced. However, since the load for the mixer is a tuned circuit resonant at the desired intermediate frequency, practically all of the other components will be unnoticeable in the output. Coupling to such a mixer circuit might be made as in Figure 9.

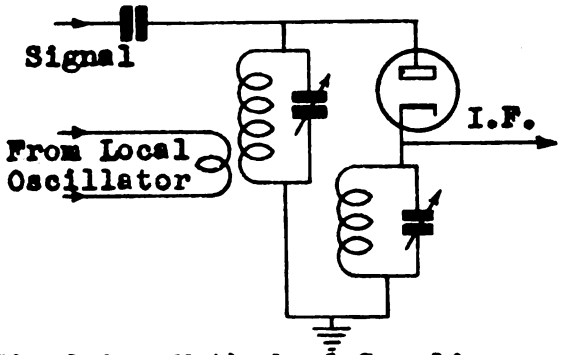

Fig.9-9: Method of Coupling to a Diode Mixer.

18. Grid Mixing: In another type of mixing the two signals are combined in the grid circuit. (See Figure 10)

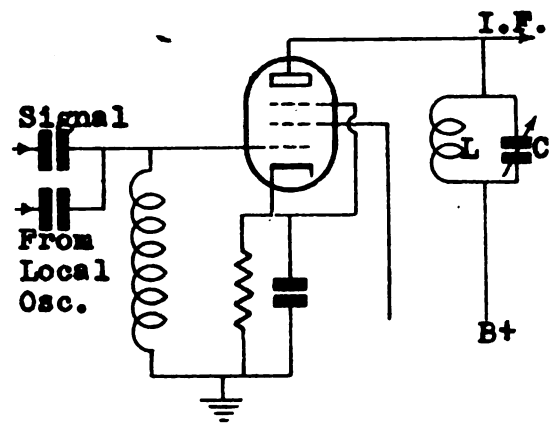

Fig. 9-10: A Grid Mixer.

By biasing the tube so that it operates near cutoff the beat between the two frequencies in the grid circuit is detected and reproduced in the plate circuit. A maximum amplitude of that signal occurs since the LC circuit is resonant at the IF frequency.

19. In some instances the local oscillator signal is placed on one grid of the mixer tube, such as the screen grid, while the signal is applied to the control grid. The effect is the

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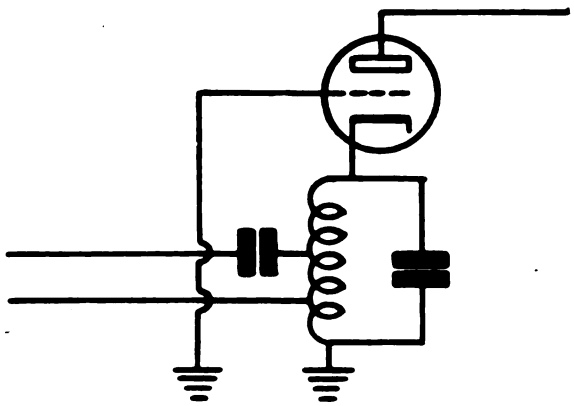

Fig. 9-11: Equivalent Crkt. Of The Grounded Grid Triode.

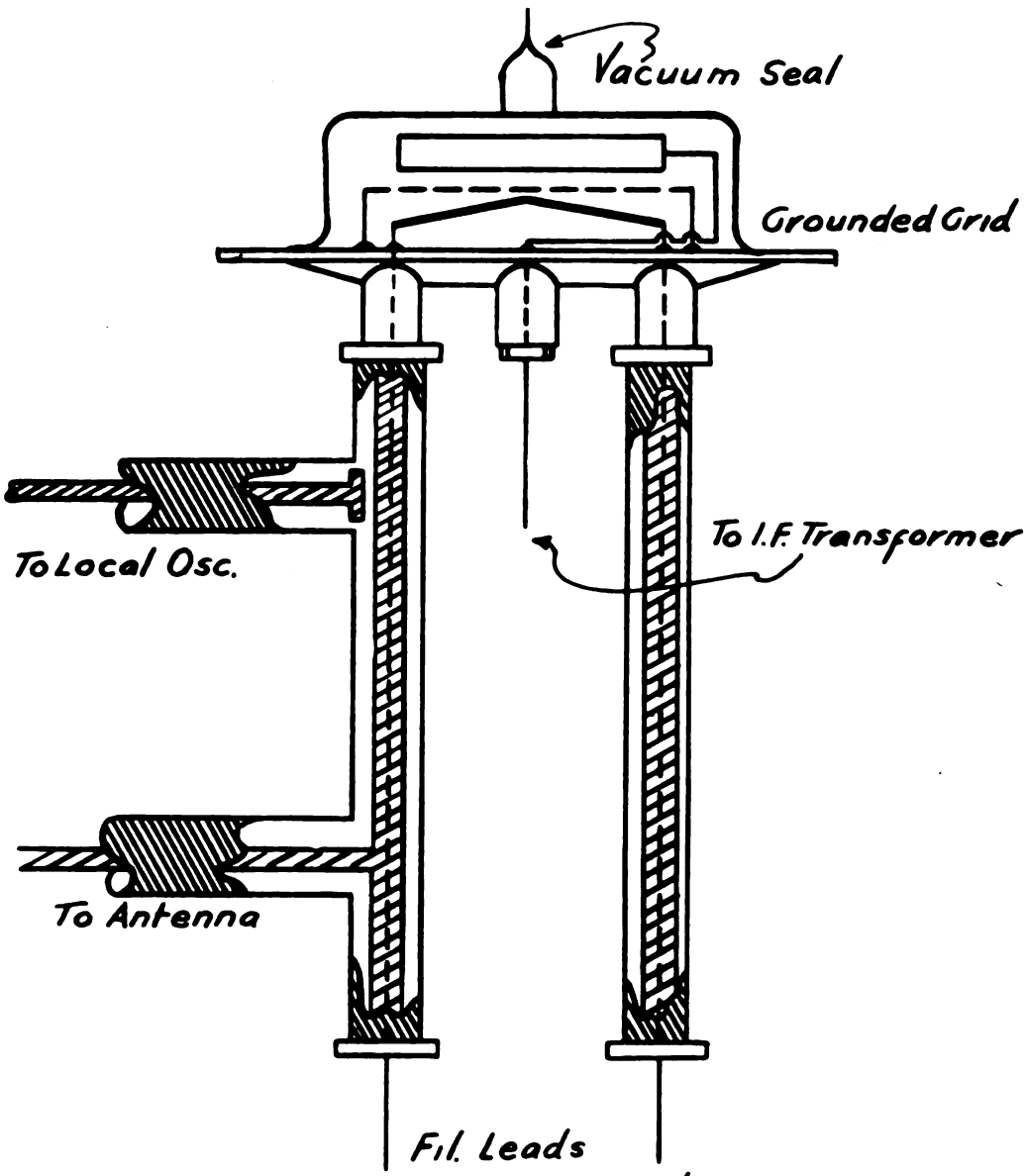

Fig. 9-12: Grounded Grid Triode

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same as produced when both signals are put into the same grid. All the components appear in the plate circuit but the desired signal, the intermediate frequency, has the greatest amplitude.

20. Grounded Grid Triode: This type of mixer is particularly suited for operation at very high frequencies in conjunction with a reflex klystron. In such a mixing circuit the operation is essentially the same as in grid mixing. The distinction between the two lies in the fact that both signals are put into the cathode circuit, instead of the grid circuit as in the case of the grid mixer. The equivalent circuit for such a mixer is shown in Figure 11. The grounded grid triode circuit is shown in Figure 12.

21. The signal is coupled into the cathode circuit at a point on the line where an exact match for the input coaxial cable may be obtained. The ouput of the local oscillator is coupled at a deliberate mismatch. This keeps the local oscillator from being loaded too heavily, prevents the signal from being swamped by too much voltage from the oscillator, and does not allow the signal to enter the line to the oscillator. This line is usually made adjustable in length so that the match at the point where the signal enters may be maintained.

22. These frequencies as well as their beat frequency will appear on the inner conductor of the line in the cathode circuit. Thus the filament voltage is varied with respect to the grid. This voltage variation on the cathode produces the same effect as a varying grid voltage when the cathode is held at a constant potential. (In this case the cathode is directly heated) Although the filament-cathode has no DC connection to the inner conductor of the coaxial line it is capacitively coupled at the end since only a small distance separates the inner conductor and the filament line.

23. By grounding the grid of the mixer tube, the plate-to-cathode capacity is decreased considerably. This is important since a very small amount of capacity at the frequency concerned results in a great effect upon the signal. The tube is unconventional only in its construction. It should be remembered that it is the difference in potential between grid and cathode in any tube which exerts the most control on the electron flow from cathode to plate. Whether the change in that voltage is made on the grid or cathode is of small consequence as long as the other element is held constant.

24. Crystal Mixers: The term "Crystal Mixer" refers not to a quartz or similar crystal exhibiting piezo-electric effect but to a combination of crystalline material such as silicon and a fine point contact of metal such as tungsten. A crystal may be used in place of a diode for diode mixing since it possesses characteristics of high resistance to current flow in one direction and low resistance to current flow in the other direction. Crystal mixers appear on the whole to have the highest signal-to-noise ratio that can be obtained in the frequency spectrum involved in microwave equipment.

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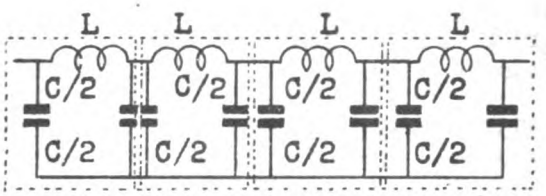
CHAPTER X

Artificial Transmission Lines

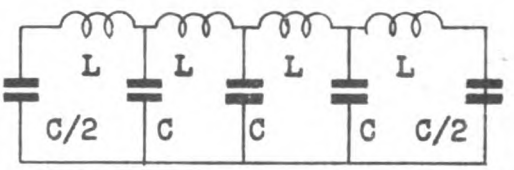
1. An artificial transmission line is any network composed of lumped constants, which can be used to introduce a time delay or to form an accurately timed pulse; it is similar to an ordinary transmission line having distributed inductance and capacity. While a transmission line is ordinarily thought of as a special conductor for high frequency energy, a given length of it may be used to produce a time delay, or to form a rectangular pulse. Consider a unit length of ordinary transmission line. If a unit voltage is applied suddenly to one end, the resulting wavefront travels down the line with a velocity equal to $1/\sqrt{LC}$. Thus whenever a brief, accurate time delay is required in Radar equipment a section of transmission line can be used to produce that delay. This characteristic (together with the fact that a section of transmission line, in charging or discharging through a matched impedance, tends to draw a constant current) is useful in the production of brief, rectangular pulses with which to excite driver-modulator systems.

2. There is one outstanding disadvantage, however, in the employment of a section of transmission line to form a pulse or to produce a time delay. Assume that a time delay of about one microsecond is required, or that a pulse of approximately one microsecond is to be formed. If the wave traverses the line with a speed comparable with that of light, it can be seen that a considerable length of transmission line will be required. Even if the required length of line were coiled up, it would be much too bulky for use in aircraft, where weight and space are limited. Fortunately, the pulse forming delay and actions of a transmission line can be simulated by a properly designed artificial line which is far lighter and much more compact.

3. The distributed inductance of a section of transmission line is usually thought of as being in series with the line, while the distributed capacity is connected across the line.



A: Artificial Line by Sections.



B: As Ordinarily Shown.

Fig. 10-1: Artificial Transmission Line.

If the total distributed capacity and inductance of a given length of line are known, it is possible to simulate that line for some purposes, by lumping the distributed capacity and inductance in the form of a small number of actual coils and condensers. Figure 1 represents such a device and is usually referred to as a "standard" line, a "normal" line or a " Section" line.

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4. Characteristic Impedance: An artificial line displays some characteristic impedance just as does an ordinary transmission line. The characteristic impedance of the artificial line is the resistive impedance which a long line would present to an electrical impulse induced in the line; it is important in determining the operation of the line in conjunction with the apparatus to which it is connected. Numerically, it is equal to the square root of the ratio of the inductance to the capacity, and may be expressed as

$$Z_o = \sqrt{\frac{L}{C}}$$

where Z_o is the surge or characteristic impedance of the line in ohms, L the inductance per section in henries, and C is the capacity per section in farads. By varying this ratio a line can be designed that will display an impedance suitable for a given application.

5. If an artificial line is terminated in its characteristic impedance, voltages applied at its input end will be dissipated by that resistance termination without reflection. If the line is open-circuited at its terminal end, any voltage applied to the input will be reflected back from the open end without change of phase, just as in the real line.

DELAY LINE

6. In many Radar equipments it is a common practice to coordinate the operation of the various units by means of synchronizing or gating pulses initiated by a central timing control. Sometimes, to improve the operation of the system, it is desirable that one unit of a system be gated a few microseconds later than another unit. An artificial line may be used to effect the required delay.

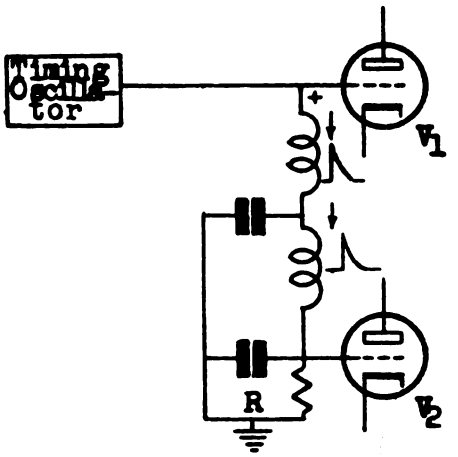

Fig. 10-2: Artificial Transmission Line Used to Introduce a Delay.

7. For example, it may be desired that V_2, of Figure 2, be operated one microsecond later than V_1. An artificial line capable of producing a delay of one microsecond is connected between the timing oscillator and the grid of V_2. R, since it is the terminating resistance of the line as well as the grid input resistance of V_2, must be equal in value to the characteristic impedance of the line if reflections are to be avoided. Each section of line produces a delay expressed by

$$t_d \text{ (per section)} = \sqrt{LC}$$

where t_d is the delay in microseconds, L is the inductance of the section in microhenries, and C is the capacity of the section in microfarads. The total delay introduced by the line is equal to the sum of the delays in each section, or

$$t_d = N\sqrt{LC}$$

where N is the number of sections employed.

8. The artificial line is similar in characteristics to a low-pass filter. Such a

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filter tends to pass all frequencies below its cutoff value, f_c, and to reject all frequencies higher than f_c. The greater the number of sections in the line the more sharply defined is the cutoff frequency, which may be expressed as

$$f_c = \frac{1}{\pi\sqrt{LC}}$$

9. Synchronizing pulses are usually either rectangular in shape, or consist of a sudden rise in potential followed by a slower exponential decay. Such waveforms contain considerable high frequency components. If the delay line is to pass such a wave without distortion, its cut off frequency must be high enough to pass the necessary frequency spectrum. Mathematically it has been proved that the time of rise for a pulse being passed through a delay line is limited to the inverse of twice the cutoff frequency.

PULSE FORMING LINE

10. In order to transmit short, powerful bursts of RF energy the transmitting tube of microwave Radar systems is modulated, or keyed, by high-voltage, rectangular pulses of very short duration. A pulse of rectangular shape is desirable because it allows the Tx tube to operate with maximum efficiency and frequency stability. An artificial line may be used to create the modulating pulse either at a low voltage -low power level (after which it is amplified by the modulator system), or directly at a high power level.

11. In Figure 3 the four condensers of the line are charged up to the potential of E_b through the high resistance of R_2. R_2 is so much larger than the characteristic impedance of the line that this end of the line may be considered to be effectively open. If the switch, S, is closed, the line abruptly begins discharging at a constant rate through R_1, which is equal to the characteristic impedance of the line. Obviously, if the network consisted of only the four condensers the discharge would follow an exponential curve and the current flow through R_1 would be anything but constant. However, by using a well designed artificial line which contains both inductance and capacity, the discharge rate can be held to a substantially constant value as long as the line is discharging.

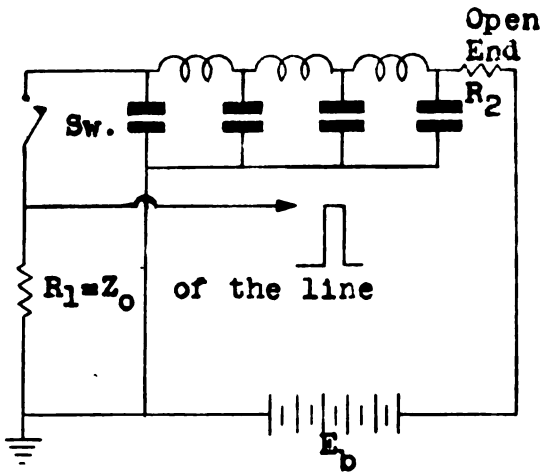

Fig. 10-3: Pulse Forming Line with a Mechanical Switch.

At the instant the switch was closed the discharge wave started traveling down the line toward the open end, causing it to lose half of its charge. Upon arriving at the open end, the wave is reflected back toward R_1. As it reaches that point, the line is completely discharged and the current flow through R_1 abruptly ceases, terminating the rectangular voltage pulse appearing across that resistance. If the switch is opened, the line charges back up to the potential of E_b.

12. Figure 4 represents a more practical version of the

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circuit of Figure 3. To effect the microsecond timing required in Radar systems the switch of Figure 3 has been replaced by a thyratron gas tube. The gas tube is normally non-conducting because of its bias potential. This allows the line to charge up to E_b through R_2. The line is switched to its terminating resistance, R_1, when a positive trigger pulse drives the gas tube into conduction. The current for this conduction is furnished by the line at a constant rate, causing a rectangular wave of voltage to appear across R_1 as long as the line discharges.

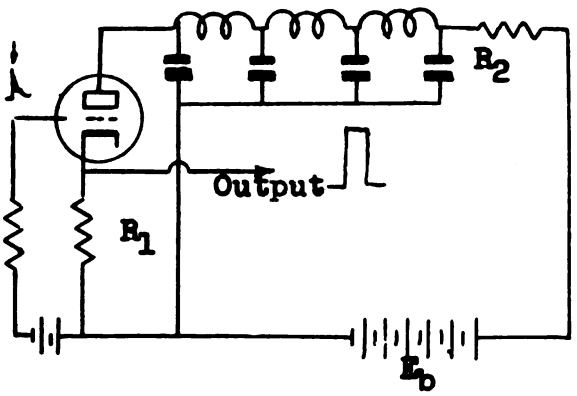

Fig. 10-4: Pulse Forming Line With Thyratron Switch.

As the line becomes completely discharged, the plate voltage of the thyratron falls below the ionization point; the tube becomes non-conductive, since E_b, in a short period of time, is unable to supply enough current through the high resistance of R_2 to maintain the plate voltage. After the tube has ceased to conduct the line again charges up to the potential of E_b. A rather long charging time can be allowed since it normally takes place during the interval between transmitted pulses.

13. The charged line might be considered as a generator with an internal EMF of E_b and an internal impedance of Z_o. At the time the thyratron fires, the line (or generator) is effectively thrown across the resistance R_1, which is equal to Z_o and in series with it. This is illustrated in Figure 5. Hence, a voltage of $E_b/2$ will appear across R_1. At the same instant a voltage wave, $-E_b/2$, will start down the line, be reflected back from the open end in phase; it will arrive back at R_1 having completely discharged the line. At this time the thyratron ceases to conduct, and the voltage across R_1 drops abruptly to zero. Thus, the potential will have been maintained across resistor R_1 during the time required for the voltage wave to travel down the line and return. It can be seen that the thyratron merely starts the action and that the time of its conduction is determined by the characteristics of the pulse forming line.

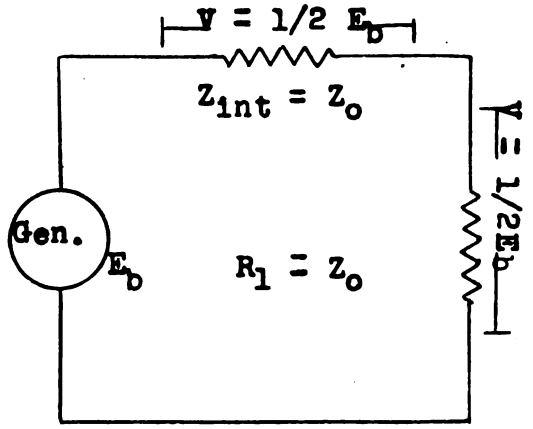

Fig. 10-5: Half the Line Voltage is Developed Across the Output.

14. In connection with the delay line it was pointed out that the time delay is equal to NTLC. However, in the case of a pulse-forming line charged to a given potential, the voltage wave must move down the line and back, thereby producing a time

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delay twice as great. Thus the width of the voltage pulse developed across the terminating resistance is determined by

$$t = 2N\sqrt{LC}$$

while the pulse repetition rate is dependent upon the frequency of the timing oscillator which triggers the switch tube.

15. A variation of the pulse-forming circuit is shown in Figure 6. Assume that the amplifier tube is normally nonconducting and that it is desired to produce a rectangular pulse of short duration at the output. The cathode resistance of the amplifier is replaced by an artificial line. The tube is put into operation by the sharp rise in voltage as the leading edge of a rectangular wave is applied to the grid. At this instant there is a sharp increase in plate current, which establishes a voltage wave between cathode and ground. This voltage starts down the line and upon reaching the open end (R_2 is very high compared to the characteristic impedance of the line), is reflected back without change in polarity, arriving between cathode and ground after a time $2N\sqrt{LC}$. This sudden increase in voltage on the cathode is sufficient to cut off the tube. Thus the leading edge of the output voltage pulse (appearing across resistance R_3) is formed as the tube is placed in conduction, and coincides with the leading edge of the pulse on the grid. The constant amplitude of the output pulse is maintained by the characteristics of the line. The trailing edge of the output pulse is formed as the line cuts the tube off at the time $2N\sqrt{LC}$; it bears no relationship to the grid voltage. After the tube is cut off, the line discharges slowly through R_2 - until the cathode voltage becomes low enough to allow the tube to conduct, or until a pulse again drives the tube into conduction, initiating a new cycle of operation.

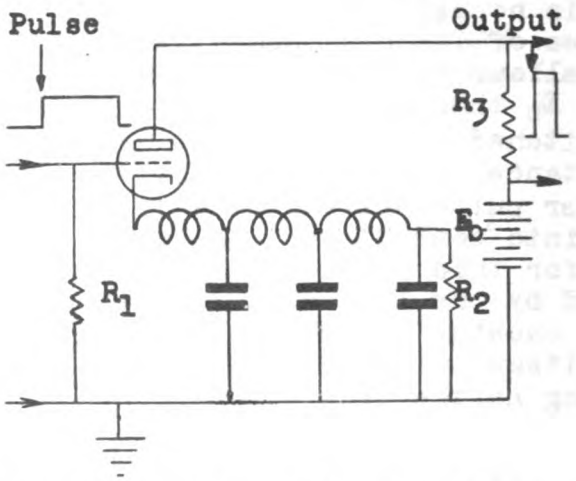

Fig. 10-6; Pulse Forming Line in the Cathode Circuit of a Tube.

16. The circuit of Figure 6 does not necessarily have to be an amplifier stage. It may well be an RF oscillator, or transmitting tube, with an artificial line in its cathode circuit. Such a line will determine the width of the RF pulse transmitted, whenever the Tx circuit is triggered by the timing oscillator.

GUILLEMIN LINE

17. The standard line is quite satisfactory when used to produce a delay, but it has limitations as a pulse-forming device. This difficulty arises from the fact that each section of the line tends to produce a hump, or ripple, in the flat top of the rectangular wave output. This effect can be minimized by using a large number of small units to obtain the required amount of inductance and capacity. The resulting ripples, while more numerous, would be of much smaller amplitude. This would result in

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some improvement, since the artificial line would then be a closer approximation to a real line. The objection to following this procedure is that the line would lose some of its compactness, as well as become more complexin design. Actually, when pulses are formed by artificial lines at low power levels and then amplified, some deviation in the pulse shape can be tolerated; this is because amplifiers can be operated so as to effect a small amount of plate limiting, and thus clip the uneven flat top before it is applied to the Tx tube.

10. When pulses are to be developed initially at high power levels for direct application to the Tx tube, there is little or nothing that can be done to improve the pulse shape when using a standard line. To meet the rather rigid pulse-forming requirements of such a situation a special type of line, the "guillemin" line, has been designed. This is shown in Figure 7. The line is charged through R_1 (which can be replaced with a choke). C_o, the main storage condenser of the line, must withstand the full potential E_b. Closing switch Sw. causes the line to discharge through R_2. The design of the line is such that, on discharge, a more nearly constant current flows through the terminating impedance than can be obtained with a standard line. Thus a rectangular wave with a more acceptable flat top is obtained. This line may be used to create pulses of very high amplitude for direct application to the Tx tube.

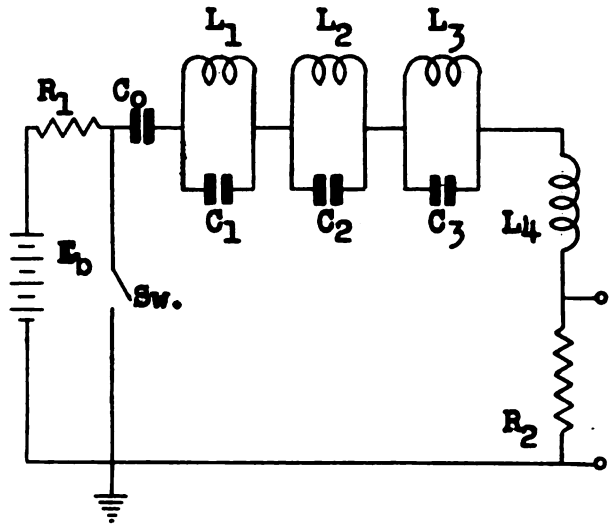

Fig. 10-7: Guillemin Line with Mechanical Switch.

19. In practical application the switch is replaced with one or more thyratrons with their cathode-plate paths in series to divide the high voltage of E_b. The discharge of the line is effected by triggering the grids of the thyratrons. R_2, in this case, is replaced by the Tx tube, and the impedance of the line and the impedance of the Tx tube are matched.

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CHAPTER XI

Driver and Modulator Circuits

1. The transmitting tube employed in microwave Radar systems is not adaptable to the self-pulsing principle discussed in Chapter V. The same results may, however, be obtained (with some improvement) by keying its plate voltage. In Radar, circuits which perform this function are referred to as "Driver-Modulator Systems". A modulator is defined as any circuit supplying power to the RF oscillator in the form of a timed, high-amplitude, rectangular pulse. A driver is any circuit which, when triggered, is designed to drive a modulator with a rectangular pulse of accurately-timed width. The driver is triggered by some form of repetition rate oscillator which determines the pulse recurrence frequency of the system. The actual shaping of the modulating pulse occurs in the driver circuit, which usually contains some type of pulse-forming network or artificial line.

2. There are two general types of driver-modulator systems; Those employing vacuum tube amplifiers, which amplify pulses generated at low voltage; and those which make use of a spark or arc discharge, generating pulses directly at a high power level. In either case the modulator must supply the power to excite the Tx tube; therefore, driver-modulator design requirements are greatly influenced by the characteristics of the Tx tube. For this reason certain characteristics of the Tx tube will be considered before describing the modulator equipment and the associated driver circuits.

RF OCILLATOR

3. For the purpose of this discussion the Tx tube may be considered to be a high impedance diode. This means that the applied plate voltage during pulses must be rather large, 14,000 volts being a typical value for present airborne equipment. When this potential is applied, it may be assumed that the tube will oscillate at or near a predetermined frequency, since its oscillatory circuit is an integral part of the tube itself. A small pickup loop within the oscillatory circuit couples the useful RF output to the transmission line or waveguide leading to the antenna. The plate of the tube is operated at ground potential for safety reasons, since it is directly connected to the metallic cooling fins surrounding the tube. This also reduces undesirable capacity to ground, since the cathode area is much smaller than the plate area. This capacity, if of any appreciable value, in charging and discharging with the application of modulating pulses might be instrumental in distorting the shape of those pulses. This is discussed in more detail later in the chapter.

4. If the voltage applied to the Tx tube is varied and those variations plotted against the resultant current flow, two significant facts are brought out: First, there is a certain level of voltage at which the tube performs most efficiently; second, as the voltage is increased to that value from zero, the tube tends to oscillate at more than one mode or frequency.

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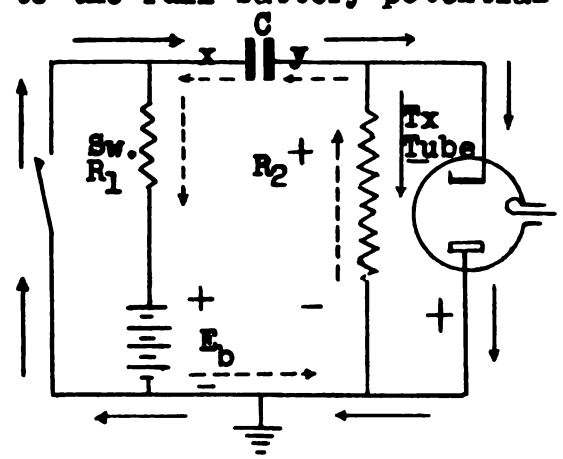
For these two reasons the modulating pulse formed in the driver should rise from its zero value to the operating level as quickly as possible, preferably in a small fraction of a microsecond, and remain at that level for the duration of the pulse. At the conclusion of the pulse it should fall back to zero in a small fraction of a microsecond, thus forming a rectangular pulse. Assuming that the modulator following the driver introduces no objectionable distortion, the Tx tube may be expected to operate with maximum frequency stability and efficiency. There is yet a third reason for the modulating pulse being rectangular in shape; it permits more accurate timing of the interval between the transmission of a pulse and the instant its reflection is received.

MODULATOR

5. As an approach to the modulator, the simple circuit of Figure 1 is presented. C is the storage condenser. It must supply the voltage and current to excite the Tx tube during pulses R_1 and R_2 are comparatively large resistors which allow C to charge up to the full battery potential



Charge ----→ Discharge ——→
during the interval between pulses.

Fig. 11-1: Elementary Modulator (Assume in this discussion a pulse width of one microsecond and a PRF of 500). No charging current flows through the Tx tube, since its cathode is positive with respect to its plate. Now consider what happens when the switch is closed. This connects side X of the fully charged condenser to ground and to the plate of the Tx tube. Since side Y is already connected to the cathode, that element is now quite negative with respect to the plate, thus driving the tube into conduction and oscillation. The small discharge current that flows through the high resistance of R_2 is of little consequence as compared to that flowing through the much lower impedance of the tube. The high potential source, E_b, is effectively removed from the circuit by the shorting action of the switch. This causes no damage, however, as the rate of current flows through the high resistance, R_1, is small.

6. Obviously, if the switch remains closed, the condenser will discharge along the usual exponential curve. The shape of the RF pulse will then be anything but the desired rectangular envelope, and will be much too wide. If, however, the switch remains closed for only one microsecond, the condenser will have released only a small fraction of its total charge, even though the discharge rate in amperes is quite heavy (See Figure 21). The resulting loss of potential at the condenser will then be such a small percentage of the original 14,000 volts that for all practical purposes the voltage applied to the Tx tube is substantially constant during the pulse. This forms the flat top of the rectangular pulse. Since the starting and stopping of the pulse are accomplished by opening and closing a switch, the pulse applied to the Tx tube will have vertical sides, thus attaining the required rectangular pulse shape. The ideal waveform is shown in

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Figure 2.

7. The mechanical switch arrangement of Figure 1 would not be practical in an actual installation, since it would not be capable of performing within the timing limitations; therefore the switching arrangement must be electronic.

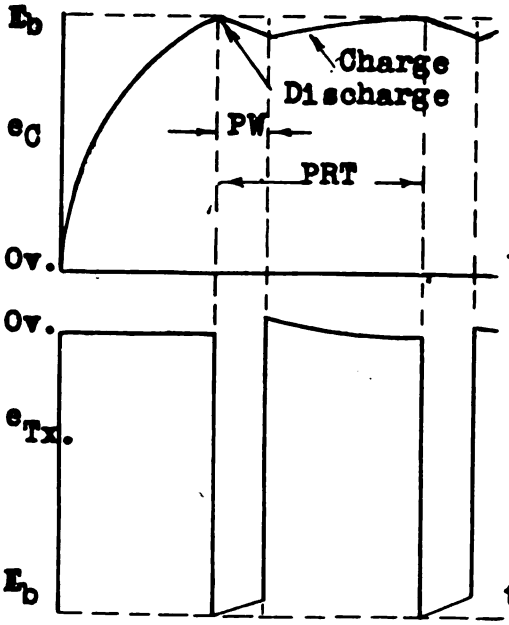

Fig. 11-2: Relation between Charge on the Storage Condenser and Voltage across the RF Oscillator.

8. In Figure 3 the switch of Figure 1 has been replaced by a vacuum tube. The bias potential applied to the grid of V_1 is sufficient to cutoff the flow of plate current. As in Figure 1, C will charge up to potential of E_b through R_1 and R_2. If a positive potential of sufficient amplitude is applied to the grid of the modulator tube, its negative bias is removed for the duration of that positive pulse; the modulator tube is driven into heavy conduction (usually to saturation), the current for this conduction being furnished by the charge stored in C. As in Figure 1, R_1 (since it is a high resistance) does not permit the supply potential to be shorted by the conducting modulator, thus very little current is actually supplied by E_b during pulses.

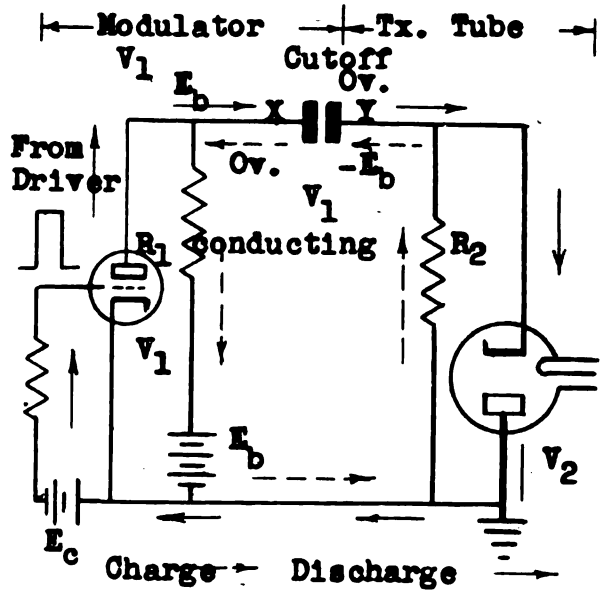

Fig. 11-3: Modulator with Vacuum Tube Switch.

The little current that does flow passes through the modulator only and thus serves no useful purpose. The modulator upon going into conduction becomes a low impedance path between side X of the storage condenser and ground. Since side X of the condenser has been virtually shorted to ground and to the plate of the Tx tube, the cathode of the Tx tube becomes quite negative with respect to its plate; conduction and oscillation result. Thus the discharge path of C involves the plate-cathode paths of both the modulator and the Tx tubes as indicated in Figure 3. While R_2 is in parallel with the Tx tube, it is such a high resistance that the small current flow through it does not constitute any serious loss.

9. Again the high voltage supplied to the Tx tube must be terminated after the desire pulse width, say one microsecond. This is effected at the grid of

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the modulator when the square wave pulse supplied by the driver drops abruptly to zero. The normal negative bias supplied by E_c through R_3 again cuts the tube off. C then charges up to the potential of E_b through R_1 and R_2 in the comparatively long period of time that will exist before another pulse is applied to the grid of the modulator tube by the driver.

10. From the foregoing discussion it is evident that the length of time the electronic switch, or modulator, allows C to discharge will be dependent upon the width of the pulse supplied by the driver. There are, however, several changes desirable in the basic modulator circuit to improve its efficiency and to insure a more nearly rectangular output pulse.

11. It has been pointed out that the high voltage pulse required to excite the Tx tube must be rectangular in shape. The waveform shown in Figure 2 represents a close approach to this ideal; however, the waveforms of a simple modulator (such as Figure 3), may not be so nearly perfect. One source of trouble is the interelectrode capacity of the oscillator tube; i.e., the capacity that exists between the cathode and the plate. In parallel with this is the capacity between the cathode external conductor and whatever grounded structure there is near it. It is to reduce this latter factor that the plate (with its large cooling fin area) is operated at ground potential, instead of the much smaller cathode. The total capacity in shunt with the Tx tube must charge up whenever a modulating pulse is applied. As a result, the leading edge of this pulse may not be vertical as desired. This would mean that the voltage across the Tx tube would not reach the operating level as quickly as it should, but would tend to linger in the zones of inefficient and off-frequency operation. When the modulating pulse is removed, this same capacity, by giving up its charge would be instrumental in preventing the sudden drop of voltage across the Tx tube. This effect is illustrated in Figure 4(A).

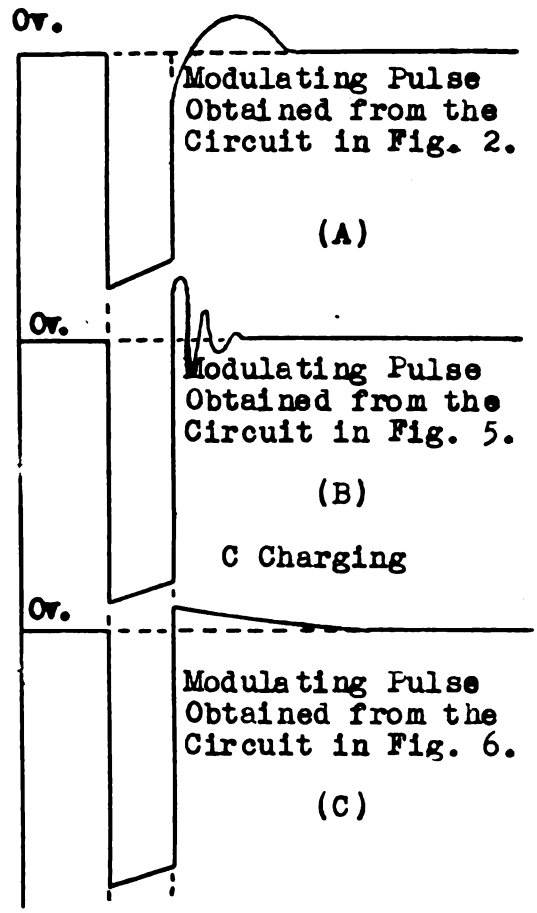

Fig. 11-4: Modulator Waveforms

12. In Figure 5, R_2 of the basic circuits has been replaced by a choke of about 10 mh. This choke, L_2, with its smaller DC Resistance insures that the storage condenser is charged to the potential of E_b in the interval between pulses. When the modulator is driven into conduction, allowing C to discharge, the discharge current will flow almost entirely through the Tx

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tube, very little getting through the parallel path, L_2, in the one microsecond pulse interval. In addition the inductive reactance of the choke tends to offset the capacitive reactance of the Tx tube's interelectrode capacity thus offering a more nearly resistive load for the modulator. This would tend to straighten the leading edge of the modulating pulse. When the pulse is removed from the Tx tube, the inductive kickback from the choke assists in cutting off the pulse sharply, since it minimizes the effect of the interelectrode capacity. This is more important on the trailing edge of the moulating pulse than on the leading edge, since the trailing edge in general seems to suffer more from capacity effects, Figure 4(B).

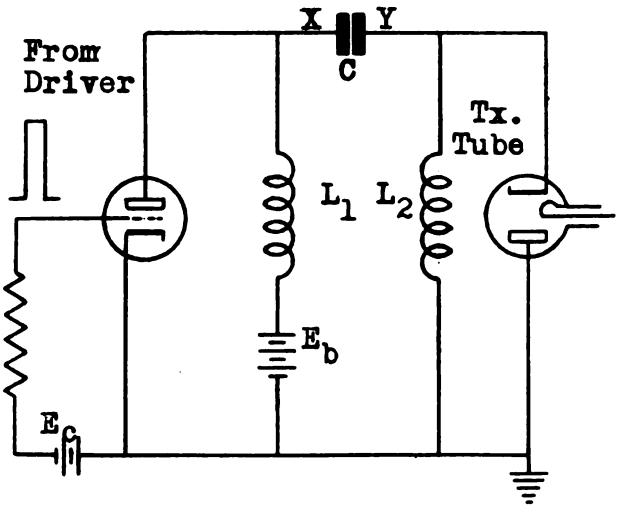

Fig. 11-5: Modulator Using Inductive Charge Path for C.

13. This corrective measure has introduced a new problem, however, since the choke and distributed capacity in shunt with it form an oscillatory circuit which is shocked into oscillation upon the removal of the modulating pulse, Figure 4(B). This cannot be tolerated, because the Tx tube would again be driven into oscillation on each negative alternation of the oscillations produced across L_2. This would cause "trailing" of the RF pulse which would limit the minimum range of the system.

14. This undesirable effect can be eliminated by the introduction of a damping diode as shown in Figure 6.

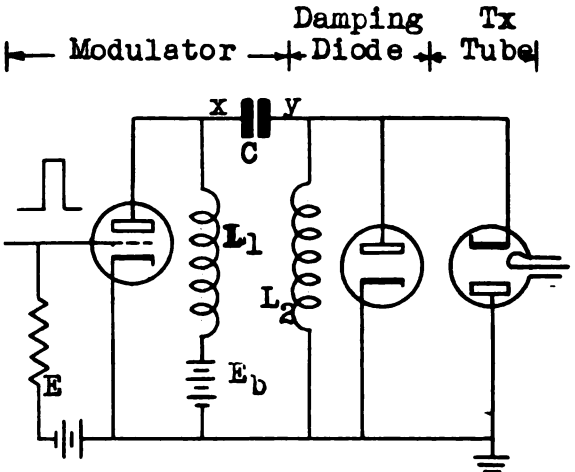

Fig. 11-6: Modulator with Damping Diode.

On positive alternations of any oscillation attempted by L and its shunt capacity, the diode conducts, quickly damping out the oscillations shown in Figure 4(B), and resulting in a modulating pulse shape as shown in Figure 4(C). Since the cathode-plate connections of the damping diode are just opposite to those of the Tx tube, no current is passed through the diode when the Tx tube is conducting.

15. In some modulators the resistor R_1 of Figure 1 and 3 is replaced with a choke, thus effecting an additional reduction in the resistance of the DC charging path of C. The reactance of the choke renders it effectively an open circuit during the brief pulse periods; therefore it does not short out the supply potential E_b.

16. It should be noted at this point that in recent models of some equipments the tendency is to revert to the basic type of modulator circuit (shown in

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Figure 3), which omits the damping diode and the inductances, L_1, and L_2, in favor of the more easily obtained resistors. The resulting loss of performance does not appear to be of sufficient importance to justify the rather expensive modifications and their accompanying procurement difficulties.

17. In the somewhat simplified drawings used thus far, the modulator has been indicated as a single tube. Actual circuits used in the past have employed two tubes in parallel to pass the heavy current flow required during pulses. Because of the excessively high voltage employed, tubes with thoriated tungsten filaments such as the 304TH were used. Filaments of thoriated tungsten require excessive current to heat them to the required operating temperature. Oxide-coated cathodes are capable of producing the required emission with much less heater current, but they are unsatisfactory because of the fact that under high voltage the oxide on the cathode tends to vaporize and settle on the grid, thus contaminating it. This is undesirable since an oxide-coated grid may become an emitter of electrons, losing its control of the plate current flow.

18. This inherent defect of the oxide-coated cathode has been overcome recently in a new type of tube known as the 715A. The grid of this tube is plated with gold. This tends to taint any oxide coating accumulating on the grid, preventing or greatly reducing the possibility of grid emission. The improved performance obtained with this tube is such that one of them may be used as the modulator in some installations.

DRIVERS

19. In the above discussion of modulators it is assumed that the modulator grid is driven by a pulse from the driver of the correct width and rectangular shape. The modulator cannot be expected to function properly with a badly adjusted or poorly designed driver. In general there are two types of drivers used in microwave Radar equipment. These are the "Bootstrap" Driver and the "Single Tube" Driver.

20. Bootstrap Driver: Figure 7 represents a typical circuit of the bootstrap dirver. It employs three tubes: V_1, a protecting or isolating diode; V_2, a gas tube (thyratron); and V_3, a high vacuum, power tetrode. The modulator tube is shown at the right in order that its relation to the driver may be seen. For simplicity of explanation the sources of all high voltage and bias potentials are represented by batteries.

21. The circuit is triggered into operation by a pulse from the timing oscillator. In the absence of any trigger pulse the voltage of B_1 is sufficient to bias the grids of V_2 and V_3 to cutoff; the modulator grid is held at cutoff by the potential of B_2. Notice that the only direct ground connection in the circuit is at the cathode of the modulator. The trigger pulse is indicated as a rapid rise in voltage, followed by a slower exponential decay. Its exact width is not critical so long as the leading edge is vertical to insure that the gas tube is triggered sharply into operation. C_2, the diode path, R_2, and R_3 constitute a short time constant as compared to the width of the trigger pulse.

22. The application of the trigger pulse to the circuit results in a sharp rise in voltage at the grid of the gas tube, triggering it into conduction. The current for this conduction must be furnished by the arti-

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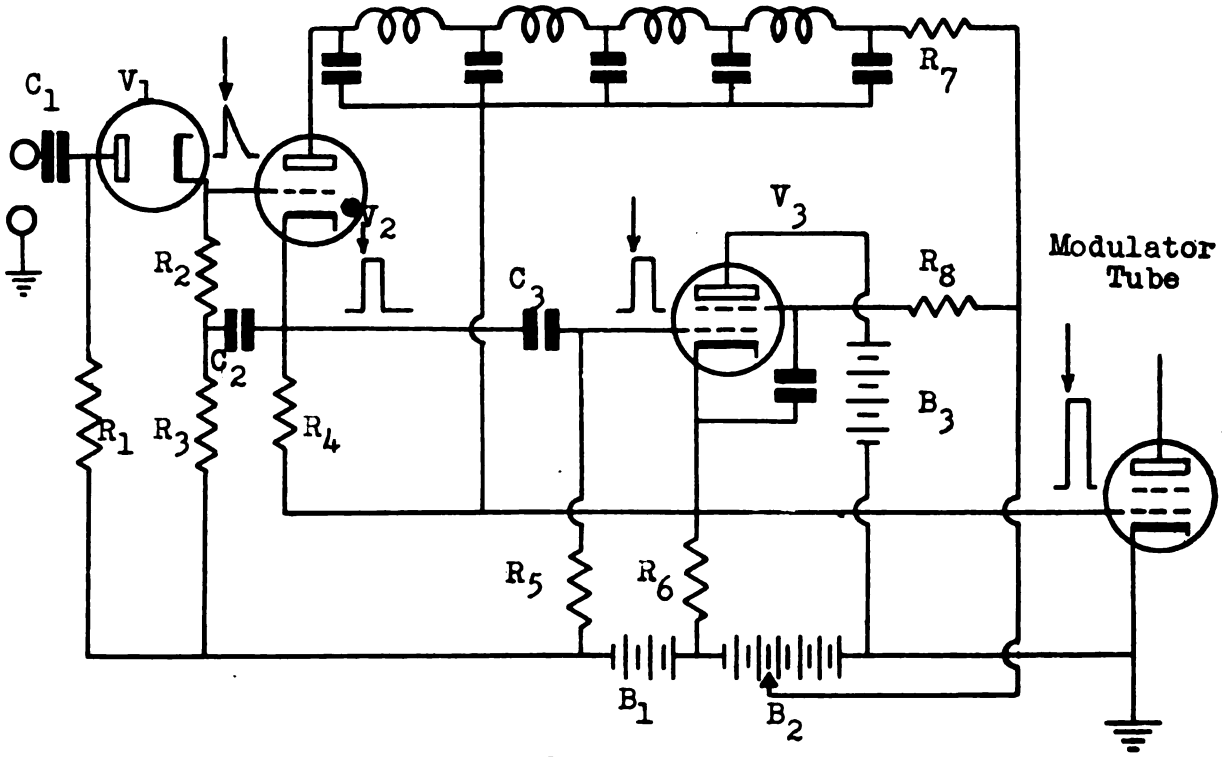

Fig. 11-7: Bootstrap Circuit.

ficial transmission line which, previous to the trigger pulse, had charged up to the potential at the tap on B_2 (through R_7). The line must discharge through the impedance of R_4 and the cathode-plate path of V_2. The impedance of this path is designed to be the same as the surge impedance of the artificial line. Therefore the instant the gas tube conducts, the voltage across the line drops to half of its original value.

23. This will be more apparent if the line is regarded for the moment as a generator of a given internal impedance. If an impedance of the same value is then switched across the generator, the voltage at its terminals drops to half its original value.

24. Returning to Figure 7, as the thyratron tube switches the artificial line to its terminating impedance, it begins to discharge at a constant rate; meanwhile, the remaining half of the voltage travels down the line as a negative wave. This wave reaches the open end and is reflected back toward the thyratron. As it reaches that tube, the line is completely discharged; therefore the plate potential drops below the ionization point, thus cutting the tube off. This will happen in spite of the connection to B_2 through R_7 because that resistance is too large to permit the passage of enough current from B_2 to maintain the voltage at the plate of V_2 during pulses. The much longer interval between pulses is sufficient, however, for the line to charge back up to the potential at the tap of B_2.

25. From the foregoing discussion it is evident that if it is desired for a voltage pulse to appear across R_4 for one microsecond the effective length of the artificial line be such that one microsecond is required for a wave to travel

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down the line and back to its starting point. Since the line discharges at a constant rate, during that period the IR drop across R_4 will be a square wave pulse of one microsecond duration. It is this pulse that is amplified in the modulator circuit and applied to the plate circuit of the Tx tube, causing it to oscillate for one microsecond.

26. Now consider the effect of the one-microsecond pulse across R_4 on the circuits that follow. This pulse is coupled to the grid of V_3, with little resulting distortion, by means of C_3 and R_5. It is of sufficient amplitude to drive V_3 from a cut-off condition into one of heavy conduction. This means that V_3 will be conducting quite heavily for one microsecond, or as long as the pulse appears on R_4. Before conduction, the cathode of V_3 was at the same potential with respect to ground as the negative side of B_2 (no IR drop across R_6). During conduction, however, it rises to a highly positive potential; that is, electrically, it is moved nearer to positive side of the series combination of B_2 and B_3. The potential of B_3 is approximately half that of B_2; nevertheless, it can be seen that if the cathode were directly connected to the positive side of B_3 it would then be positive with respect to ground. This extreme is, of course, not possible because the plate-cathode path of V_3, when conducting, is not a perfect conductor, so there will be a comparatively small voltage drop across it. Therefore the actual cathode potential with respect to ground will depend on the ratio of the resistance of R_6 to the resistance of the plate-cathode path of V_3.

27. The latter becomes sufficiently small during conduction to allow the cathode to become quite positive with respect to ground. It must be remembered, however, that the cathode of V_3 before conduction was highly negative with respect to ground. Going from ahigh negative value to a rather high positive value means a large total voltage variation. In actual circuits it may be as much as a thousand volts or more. Since the only point in the circuit that is grounded is the junction of B_2, B_3 and the cathode of the modulator, the entire circuit of V_3, (including the gas tube and its pulse shaping line) rises above ground during the pulse voltage (1000 volts or more). This accounts for the colorful name, "Bootstrap" circuit, for it literally pulls itself up to a very high voltage by its bootstraps. (Figuratively speaking, the position of the cathode of V_3 is comparable to that of a "bootstrap").

28. The high-voltage rectangular pulse developed across R_6 is coupled directly to the grid of the modulator. The latter is driven from cutoff to saturation, applying a very high negative voltage to the cathode of the Tx tube, causing it to conduct heavily and oscillate for the desired pulse duration.

29. Notice that V_2, V_3, and the modulator are cathode-coupled and biased to cutoff between pulses. It would have been possible to arrange the load impedances so that the useful output could be taken from the plate circuits of V_2 and V_3 and still obtain a positive pulse to drive the modulator. It would have been necessary, however, to allow V_3 to conduct during the longer period between pulses to obtain the polarity inversion necessary in this instance. By operating with all driver-modulator tubes non-conductive between pulses, a considerable reduction in power consumption and power supply requirements can be made, together with increased tube life.

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30. V_1 is called the protective, or isolating, diode. As its name implies, it isolates the driver stage from the trigger circuits preceding it. Positive trigger pulses in charging up C_1 cause the plate of the diode to become positive with respect to its cathode. It conducts, thus passing the trigger pulse to the grid of V_2. C_1 is charged very quickly by this action and, after the removal of the applied positive trigger voltage, will tend to discharge. If the diode were not present, this would cause the grid of the thyratron to become even more negative than its bias voltage. This might result in positive ion bombardment within the gas tube thus shortening its useful life. With the diode present, however, the negative potential is blocked, since V_1 will not conduct with its plate more negative than its cathode. The condenser is then forced to discharge through R_1. Aside from this, it will be recalled that when V_3 conducted, the high voltage pulse appeared at its cathode, causing the entire circuit of V_2 to be lifted to a high potential. This surge might cause some ill effects on the preceding trigger circuit, if it were not for the isolating diode which will not pass this positive potential (since its cathode becomes more positive than its plate).

31. Note that a condenser, C_2, is connected from the cathode of V_2 to the lower side of R_2. This is necessary because as the cathode of V_2 goes positive during pulses, the entire potential developed across R_4 and R_6 during pulses, plus the already present bias potential of B_1, would drive the grid of V_2 quite negative with respect to its cathode, once triggered into conduction. This would result in the injurious positive ion bombardment mentioned above. Connecting the grid to the cathode, via C_2, the grid will rise as the cathode rises, thus avoiding an excessively negative grid potential yet still permitting enough potential to be developed across R_2 during the trigger pulses to drive V_2 into conduction.

32. Single Tube Driver: Somewhat more recent developments have resulted in a driver circuit which required but a single tube. In Figure 8, the tube (actually a double beam tetrode with both sections in parallel) is biased to cutoff between pulses.

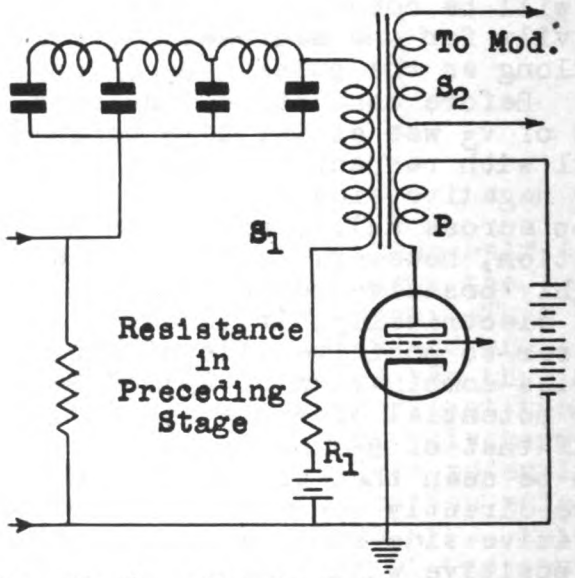

Fig. 11-8: Single Tube Driver.

The action is initiated by a positive trigger pulse from the timing oscillator. The positive pulse voltage tends to increase the charge already on the artificial line due to the presence of the bias battery. This causes the line to begin changing its level of charge to equal the new value of potential.

33. This is true in spite of the inductive reactance of C_1, inasmuch as there is enough distributed capacity across that

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winding to permit the trigger pulse to be instantaneously effective on the grid of the tube. The applied pulse renders the grid of the tube less negative, driving it into conduction. As a result of this conduction through the primary of the transformer, a sharp rise in voltage appears across the secondaries, forming the leading edge of the pulse. The new high voltage now present across S_1 reinforces the positive trigger pulse carrying the grid further in the positive direction and increasing plate current flow through the primary which continues to build up its magnetic field.

34. The result of the regenerative action under way is that plate current flow through the primary increases along the usual exponential curve as rapidly as its inductive reactance will permit. For all practical purposes the first part of this curve may be considered linear. Later it will be seen that the artificial line will interrupt this action before the curve becomes too non-linear. For the moment, the current through the primary is increasing at a substantially constant rate, which maintains a constant voltage at both secondaries, and so forms an acceptable flat top for the rectangular output pulse. The voltage across S_2 is considerably higher than that across S_1 because of its higher turns ratio with respect to the primary.

35. The artificial line is now charging to the new high potential developed across S_1. Since the grid is actually positive with respect to the cathode, the charging current's completed path to the line includes the grid-cathode path of the tube and whatever impedance there is at the input of the circuit due to the preceding stage. As the line continues to charge at a constant rate, the current flow in the primary increases at a constant rate, thereby maintaining a constant voltage across the secondaries. The pulse is terminated as the artificial line becomes fully charged. The latter then has a potential equal in amplitude and opposite in polarity to that across S_1; it is, therefore, effectively an open circuit.

36. This means that charging current through the cathode-grid path of the tube ceases abruptly, allowing the grid to fall in the negative direction. Plate current flow through the primary will likewise begin to fall off at this point. This causes the voltage across the secondaries to fall abruptly since the lines of force about the primary no longer increase; and as those lines of force collapse, a new high voltage of opposite polarity appears across the secondaries. Since the voltage across S_1, is reversed, it now tends to bring about the discharge of the artificial line. The line can therefore no longer be regarded as an open circuit for the moment, the potential it had already acquired is in series with the potential across S_1, driving the grid of the tube sharply beyond cutoff. Once cutoff, the tube will be maintained in that condition by the normal bias potential.

37. Thus it is seen that the initial sharp rise across the output secondary, S_2, results from the flow of plate current through the primary, as the tube is thrown into conduction. The constant voltage level, or flat top, is maintained by the linearity of the current rise through the primary. The sharpness of the trailing edge of the output pulse is due to the action of the artificial transmission line, which controls the time that the driver tube remains in a state of conduction.

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38. In the driver-modulator systems discussed thus far the modulating pulse is created at a low-voltage, low-power level and then amplified until it is sufficiently powerful to be applied to the plate circuit of the Tx tube. The artificial line used was the standard type which does not develop as perfect a rectangular wave as compared with the larger heavier and more expensive Guillemin line. This was no particular disadvantage, because the driver and modulator following the line were operated in such a non-linear manner as to correct for any outstanding deficiencies in the pulse shape. This is particularly true in the bootstrap circuit, in which both the second driver tube and the modulator are driven to saturation. This would tend to produce a modulating pulse with the desired flat top by plate limiting, even though the pulse forming line were deficient in that respect. There are other systems for creating the modulating pulse initially at high power levels for direct application to the Tx tube. These have the outstanding advantage of eliminating the modulator tubes with their heavy current drain. Once the pulse is generated, however, there is little or nothing that can be done to improve its shape. For this reason the ordinary type of line is replaced by a Guillemin line which provides a more rectangular pulse.

39. Figure 9 illustrates one form of surge generator. The condensers are charged in parallel through the various inductances from the high potential source, E_b. As the potential on the condensers rises to a sufficiently high value, the spark gaps break down and form a comparatively low resistance discharge path for the condensers (now effectively in series instead of parallel). The chokes because of their reactance may for the moment be considered as open circuits.

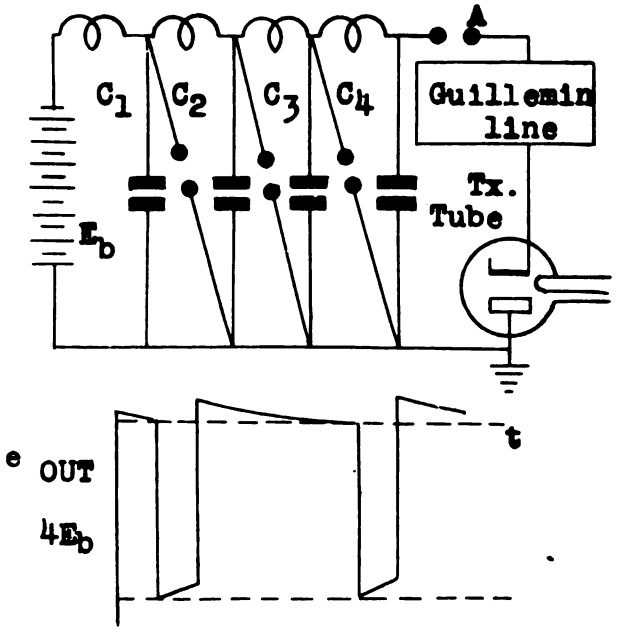

Fig. 11-9: Surge Generator.

This means that the potential applied to the Guillemin line and Tx tube is approximately four times the potential on any one condenser, assuming that all condensers are of the same capacity. The artificial line, charging at a constant rate through the Tx tube, causes the latter to oscillate. As soon as the line becomes charged to the potential supplied by the condensers in series, it is effectively an open circuit. This extinguishes the spark gaps, abruptly terminating the power supplied to the Tx tube, and consequently its oscillation. The condensers again charge up in parallel through the inductances replacing the amount of charge lost. The voltage on the condensers builds up until the spark gaps break down, discharging the condensers in series and starting another cycle of operation.

40. The above system obviously is not synchronized by

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any external circuit. Its repetition rate or pulse recurrence frequency is a function of its own natural breakdown rate. This may be altered by changing the size of the condensers or the chokes. Synchronization of systems such as this may be effected by employing a rotary spark gap. This gap would replace the fixed gap A. A rotating gap consists of one or more fixed electrodes and one or more rotating electrodes. Breakdown occurs when a rotating electrode moves sufficiently close to a fixed electrode to cause breakdown of the air gap. The spark repetition rate is proportional to the number of revolutions per second, once the number of fixed electrodes and the number of moving electrodes is established. The repetition rate can most readily be controlled by varying the speed with which the moving electrodes are rotated.

41. A more accurate method of timing the breakdown of the spark gaps would employ a thyratron instead of gap A. The partial discharge of the condensers would then be initiated by a trigger pulse from some repetition rate control to the grid of the thyratron. Because of the high potentials employed it would probably be necessary to employ more than one thyratron in series to divide the voltage.

MEGAWATT PULSE MODULATION

42. The maximum range of Radar Equipment increases only as the fourth root of the power. This would seem to indicate that high power is not worth the expense and added weight of the equipment. However, the signal-to-noise ratio at a given range is multiplied by the square root of the power ratio. This makes for clearer signals and many reflections that would ordinarily be lost in the "grass" would become usable with a substantial increase in power. Thus, high power seems to be warranted in some cases since it does increase the performance within the range already obtainable. To obtain the enormous pulse power of over a million watts there are two systems available. The first employes an arrangement of hard vacuum tubes, one type resembling two bootstrap circuits in cascade. The second is a high-powered version of the spark gap or arc, similar to Figure 9. A spark gap can withstand many thousands of volts before breaking down and can carry many amperes when conducting.

PULSE TRANSFORMER

43. One device which has contributed greatly to the flexibility and efficiency of Radar installations is the pulse transformer. This is a special transformer designed to pass narrow rectangular pulses with a minimum of distortion. It is possible to use it as a polarity inverter whenever required or to transform pulses from one impedance level to another. The Tx tube may be located some distance from the modulator by using a coaxial cable to transfer low voltage, high current pulses from the modulator to the vicinity of the Tx tube. A pulse transformer between the termination of the line and the Tx tube steps up the voltage to work into the high impedance of the tube. Thus greater flexibility in the location of modulator and Tx is attainable; an important item in airborne gear.

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CHAPTER XII

Limiter Circuits

1. A limiter circuit is one which limits or clips either or both the positive or negative portion of a waveform at a predetermined level.

2. Uses: Limiters are useful in wave shaping circuits where it is desirable to square off the top and or bottom of a pulse, in frequency modulation receivers where it is necessary to limit the amplitude of the signal applied to the detection system to a constant value, and in any circuit in which the production of pulses of even amplitude is required.

DIODE LIMITER

3. Consider the characteristics of a simple diode tube. If the plate is held at some potential which is positive with respect to its cathode, the diode will conduct. If this positive potential is increased, conduction through the tube will be increased. Remember that while the tube is conducting it acts like a very low resistance. If the conduction increases, this resistance will fall still lower. It may be said that while it is conducting, the diode presents a short circuit to the generator. On the other hand, if the plate is driven negative with respect to the cathode, the diode will not conduct and its resistance become infinitely large. In this case the diode acts as an open circuit.

4. Consider the results of applying a positive potential to the circuit in Figure 1. The diode will conduct, causing a current to flow through it and through the resistor in the plate circuit. Since the resistance of the series resistor is large compared to the resistance of the diode, practically all of the positive voltage will appear as an IR drop across the plate resistor. This IR drop will subtract from the applied potential and the output will therefore be practically zero. If, on the other hand, a negative potential is applied to the circuit, there will be no current flow through the diode and consequently no IR drop will appear across the resistor. In this instance the output will be the same as the input.

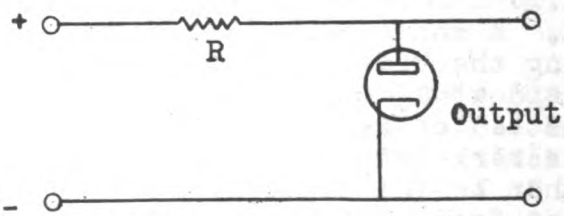

Fig. 12-1: A Diode Circuit Which Limits the Positive Voltage Swing.

5. With the foregoing discussion in mind, consider what will happen to a sine wave of voltage applied to the circuit of Figure 1. During the positive portion of the cycle the diode conducts and the output is only very slightly positive. See Figure 2. (Remember that while the diode is conducting its resistance is very small, but not zero. This will account for the slightly positive portion of the output waveform as shown in Figure 2) During the negative alternation of the cycle the diode will not conduct and the waveform will not be altered.

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The circuit in Figure 1, therefore, will limit the positive portion of any waveform that might be applied to it.

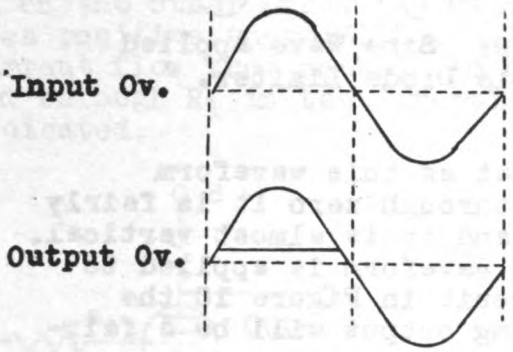

Fig. 12-2: Limiting of the Positive Voltage Swing.

6. Now consider what will happen if the plate and cathode connections in the circuit of Figure 1 are interchanged. This condition is shown in Figure 3.

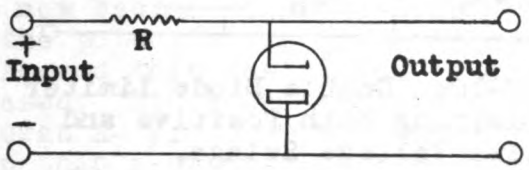

Fig.12-3: A Diode Circuit Which Limits the Negative Voltage Swing.

In this case as the applied waveform goes positive it will not be altered, but as it goes negative it is limited to a point just below zero. This circuit is then said to have limited the negative portion of the waveform. See Figure 4.

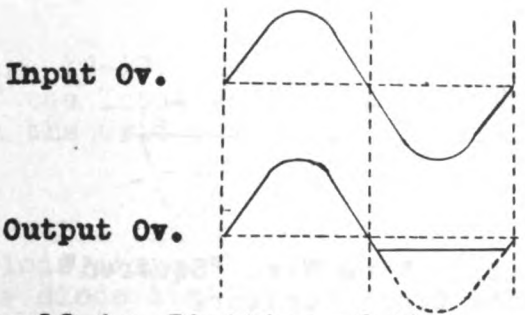

Fig.12-4: Limiting of the Negative Voltage Swing.

7. So far limiting of either positive or negative portions of waveforms has occured essentially at the zero reference point. Consider the operation of the circuit if a battery is added to the limiter as shown in Figure 5.

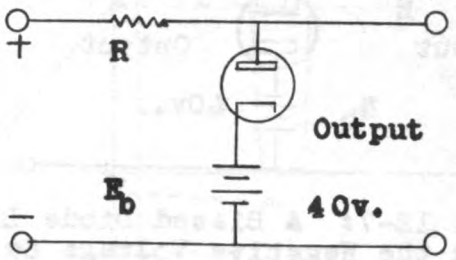

Fig. 12-5: A Biased Diode Limiting the Positive Voltage Swing.

The diode plate now has to go positive by an amount determined by the potential of the battery before the tube will begin conducting, in this case 40 volts. Therefore the output voltage rises to plus 40 volts on the positive swing of the input voltage. The diode starts to conduct at this point, producing an IR drop across the series resister which "limits" or prevents any further rise of the output voltage. The effect on a sine wave input is shown in Figure 6.

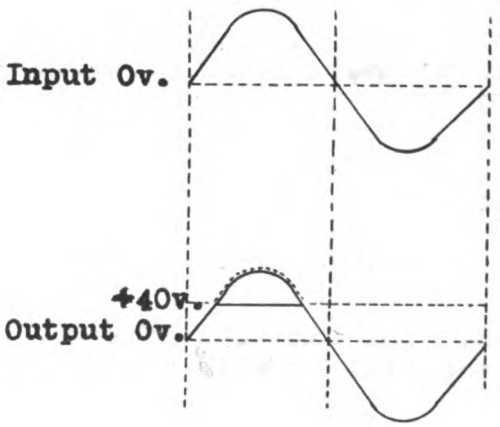

Figure 12-6: The Limiting Effect of a Diode Limiter with a 40 volt Bias.

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By a similar circuit arrangement the negative portions of the waveform can be limited at some negative potential, as shown in Figure 7 and Figure 8.

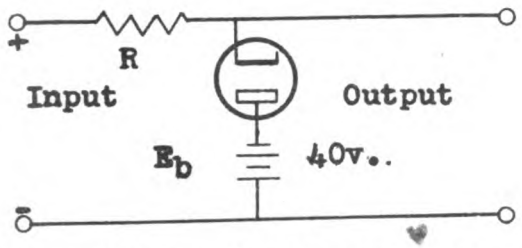

Fig. 12-7: A Biased Diode Limiting the Negative Voltage Swing.

8. Applications of Diode Limiters: Suppose that it is necessary to limit a series of positive pulses, that range in amplitude from 90 to 100 volts, to some lower potential. As an example, assume this lower potential to be 40volts. If the waveform is applied to the circuit in Figure 5, and the value of E_b is made 40 volts, then the output will be a series of positive pulses, each of which rises to 40 volts in amplitude. Notice that although the input pulses may have varied in height, they now have been limited to the same amplitude.

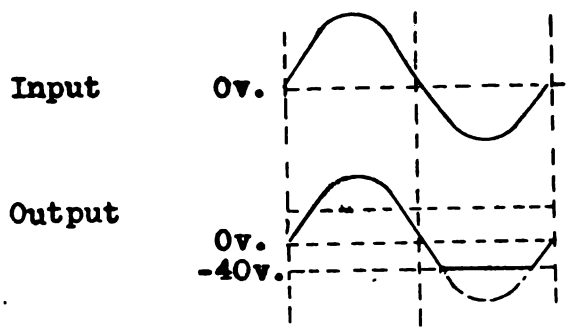

Fig.12-8: The Limiting Effect of a Diode Limiter with a -40volt bias.

9. As a second application of the diode limiter, consider the sine wave shown in Figure 9.

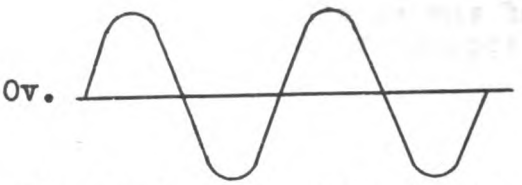

Fig.12-9: Sine Wave Applied to Double Diode Limiter.

Note that as this waveform passes through zero it is fairly linear and it is almost vertical. If this waveform is applied to the circuit in Figure 10 the resulting output will be a fairly good square wave.

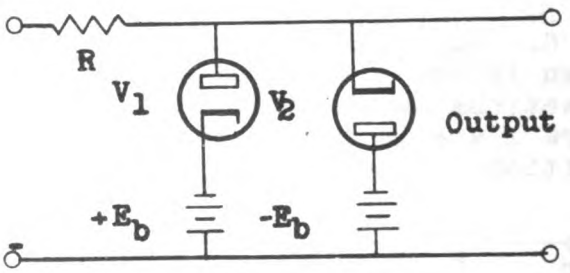

Fig.12-10: Double Diode Limiter for Limiting both Positive and Negative Voltage Swings.

The positive portions of the waveform will be limited by V_1 at a point determined by E_b, and the negative portions will be limited by V_2 at a point determined by $-E_b$. If the sine wave input is large in amplitude and the values of E_b and $-E_b$ are comparatively small, the sides of the resultant wave will be almost vertical, as shown in Figure 11.

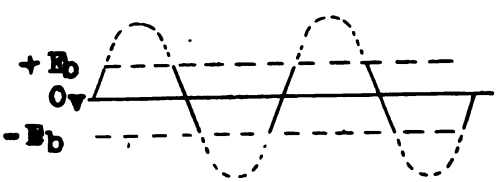

Fig.12-11: Sine Wave "Squared" by Double Diode Limiter.

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TRIODE LIMITER

10. In the circuit shown in Figure 12, as long as the grid is negative with respect to the cathode, the grid to cathode resistance is infinitely large. If on the other hand, the grid goes positive there will be a current flow from cathode to grid and through R_1 in the direction indicated.

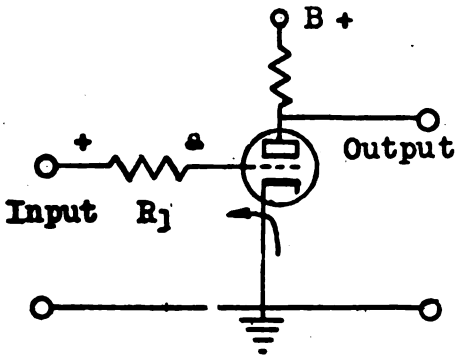

Fig. 12-12: Triode Limiter

The grid to cathode resistance has now become very small and as the potential on the grid is increased this resistance is decreased. Since the current flow through R_1 produces a voltage drop that subtracts from the input voltage, the grid will remain constant at approximately zero potential. Figure 13 shows the waveform appearing on the grid when a sine wave of voltage is applied across the input terminals.

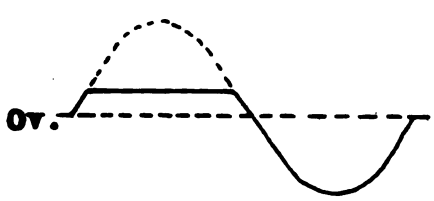

Fig. 12-13: The Positive Swing of the Input Voltage is Limited in the Grid Circuit.

11. This portion of the triode circuit can be compared to the diode limiter shown in Figure 1, since the action in the grid circuit is exactly the same.

Analyzing the circuit shown in Figure 12 a step further, consider the e_g/i_p curve of Figure 14.

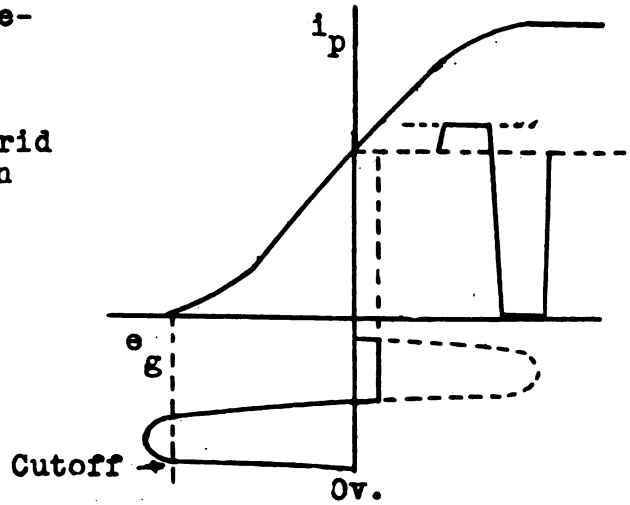

Fig. 12-14: The e_g/i_p Characteristics of a Triode.

The negative portion of the grid waveform will produce a corresponding decrease in plate current until cutoff is reached. Since at cutoff, plate current has ceased to flow, any further swing of the grid in a negative direction will have no further effect upon the plate current waveform. Actually the negative portion of the plate current waveform has been squared due to the fact that the grid was driven beyond cutoff. The square wave of plate current, thus obtained, will produce a corresponding square wave of voltage across the output of the circuit. Remember, however, that the output voltage waveform will be inverted with respect to the plate current waveform.

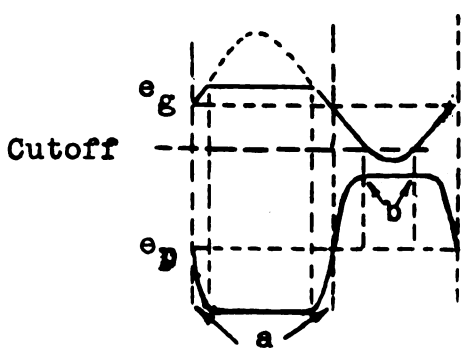

Fig. 12-15: Sine Wave Voltage "Squared" by Grid & Plate Limiting.

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12. By limiting action in the grid circuit and by limiting action due to plate current cutoff, a square wave has been obtained from a sine wave input. However, this square wave is not perfect. In the first place, the sides of the sine wave are not absolutely vertical. Also, there is some small amount of rounding of the negative portion of the waveform, point "a" Figure 15. This is due to the fact that there is a small amount of voltage division between the grid to cathode resistance and the resistance of R_1 (Figure 12). The positive portion is somewhat rounded due to the small curvature of the e_g/i_p curve around the cutoff region, point "b" Figure 15. It may be necessary to sharpen this waveform further.

13. If this somewhat imperfect square wave is applied to the circuit of Figure 16 consider what will occur. The first positive portion will drive the grid positive with respect to the cathode. Immediately the grid will draw current and condenser C will be charged through the tube. The charge on C will be equal to the amplitude of the input signal.

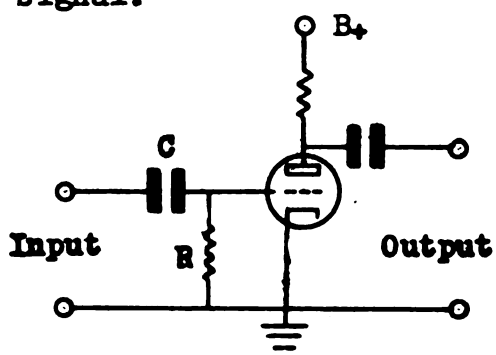

Fig. 12-16: Amplifier Stage Following A Limiter Circuit.

The grid has returned to zero potential. As the positive portion of the square wave is removed the grid is driven negative by an amount equal to the charge on the condenser. The condenser will now try to discharge through the resistor R. This resistance-capacity combination forms a long RC circuit however, and the amount of discharge will be very small. As the waveform swings positive again the grid will be driven back up to zero. Any amount of charge that leaked off the condenser will be replaced while the waveform is positive. If the grid goes positive by any amount the condenser will recharge through the low grid to cathode resistance of the tube.

14. The grid waveform is shown in Figure 17.

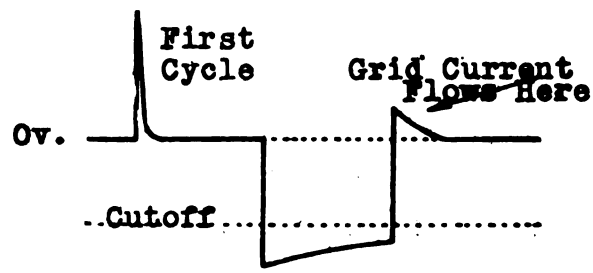

Fig. 12-17: Waveform at the Grid of the Grid and Plate Limiter in Figure 16.

Note that after the first positive swing of the input waveform the grid never goes positive but by a very small amount. Thus the grid waveform has been "clamped" so that essentially all of it appears below the zero reference line. Observe the cutoff point of the tube in Figure 17. Again the waveform will be limited by plate current cutoff.

15. The output of this stage will be a comparatively good square wave. The sides have become practically vertical due to amplifying and limiting. The positive and negative portions have been squared due to grid limiting and to plate current cutoff limiting. The plate voltage will vary between E_b and the value of e_p when e_g is zero.

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CHAPTER XIII

Clamping Circuits

1. A clamping circuit is one which takes a waveform at either amplitude extreme and transfers it to a given reference level of potential. The circuits may be divided roughly into two classifications. The first, diode and grid clamping, clamps either amplitude extreme and allows the waveform to extend in only one direction from the reference potential. The second, synchronized clamping, maintains the output potential at a fixed level until, a synchronizing pulse is applied at which time the output potential is allowed to follow the input. At the end of the synchronizing pulse the output voltage is returned immediately to the reference level.

2. Necessity for Clamping: In order to see why clamping circuits are necessary it is desirable to review briefly the action of coupling networks. In coupling from one stage to another in radio and radar work, it is almost always essential that a coupling condenser be used to keep the high positive D.C. plate potential of the first tube isolated from the grid of the second tube. Only the varying component of the plate potential is to be transmitted to the grid as a voltage varying above and below some fixed reference level. See paragraphs 22 to 29, Chapter III. If the low end of the grid Resistor is grounded, the grid voltage (with respect to ground) will vary about zero. If a biasing potential is employed, signal applied to the grid will vary above and below this D.C. biasing voltage.

3. In class A operation this latter condition is desirable. The biasing potential is adjusted to the center of the Class A "range", and the varying potential is kept within the limits of this range. The center of the grid swing is fixed, and variations in the amplitude of grid swing directly affect the amplitude of plate swing, which is exactly what is desired for class 'A' operation. See Figure 1 (A).

4. In some other circuits, however, it is necessary that the waveform swing entirely above or entirely below the reference line, rather than alternate about it. See Figure 1 (B and C). For these applications a clamping circuit is used to clamp either the positive or the negative extreme of the waveform to the desired level.

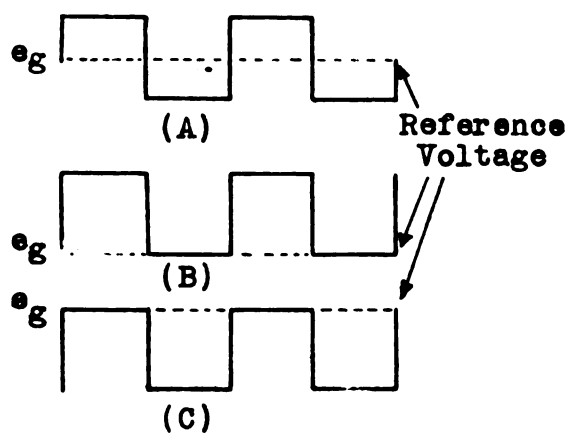

Fig. 13-1: Grid Voltage Variation With Respect to A Definite Reference Voltage.

5. The output of an ordinary RC coupling circuit is alternating in character because the average voltage level of the applied waveform is zero. For a full discussion of this action refer to Chapter III on RC circuits.

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After the coupling condenser has charged to the average applied voltage any decrease in applied voltage will cause the output voltage of the RC network to swing negative. Any increase above the average will cause the output voltage to swing positive.

6. Now, if the condenser could be made to charge, say, to the minimum applied voltage and no more, any swing would have to be in a positive direction, and the output voltage would vary between zero and some positive value. On the other hand, if the condenser could be made to charge to the maximum applied voltage and remain charged to this level, any swing would necessarily be in the negative direction, and the output voltage would vary between zero and some negative value. In the first case the bottom of the output waveform is clamped to zero; in the second, the top of the waveform is clamped to zero.

DIODE CLAMPING

7. Consider the case where the condenser voltage is maintained at the minimum applied voltage. The simplest means of accomplishing this is illustrated in Figure 2.

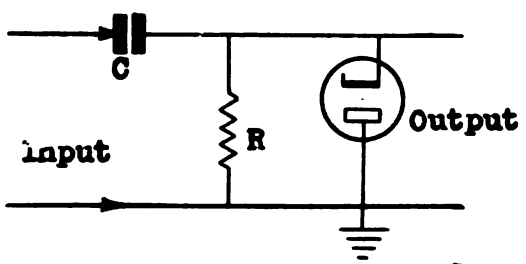

Fig. 13-2: Diode Clamping Circuit with Plate Grounded.

It will be noted that the only thing added to the ordinary RC coupling circuit is a diode. In order to understand the action of this circuit it is necessary to remember one thing: If the cathode of a diode is made negative with respect to the plate (Plate positive to cathode), current will flow from cathode to plate, and the tube will constitute a low resistance; whereas if the cathode is made positive with respect to the plate (plate negative to cathode), no current will flow and the tube may be considered an open circuit.

8. Assume that the input to the circuit of Figure 2 is obtained from the plate circuit of a tube which is generating a square wave. The waveform at the clamping circuit might be as shown in Figure 3.

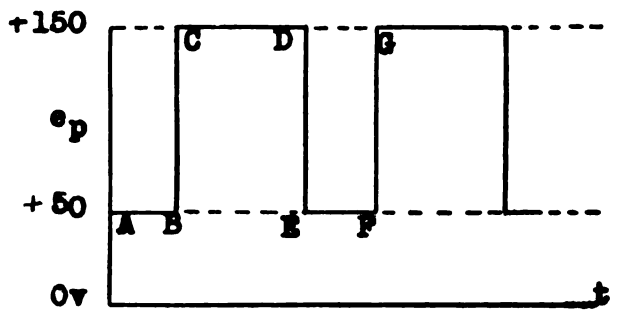

Fig.13-3: Typical Plate Voltage Applied to Clamping Circuit.

Referring back to Figure 2, condenser 'C' will charge gradually through the high resistance 'R'. After a period, depending on the time constant of the RC circuit, the charge on the condenser will reach fifty volts, the base of the input waveform. The problem is to maintain the voltage at this level in spite of the tendency of the condenser to charge to a higher level when the applied voltage is at +150.

9. Assume that the voltage has been applied for some period of time previous to point 'A' of Figure 3, and that the condenser charge has reached fifty volts. During the time between 'A' and 'B' the charge on the condenser will be equal to the

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applied voltage, and no current will flow. Then, at point 'B', the applied potential suddenly rises to 150 volts. Since it is impossible to change instantaneously the potential difference across a condenser, and since no time elapses between points 'B' and 'C', the condenser voltage must still be fifty volts. The difference between the +150 volts applied and the condenser charge of 50 volts must appear across 'R'. This difference of 100 volts becomes the output voltage.

10. The fact that a voltage appears across 'R' indicates that there is current flowing through it. This current adds to the quantity of electricity stored in 'C' increasing its charge. Ordinarily the time constant of RC would be very long and the added charge would be extremely small. For simplicity, assume that the 150 volt potential is applied for a time equal to one-tenth RC (point 'C' to point 'D'). Remember that the cathode of the diode is positive with respect to its plate, so the diode acts as an open circuit, and 'R' is a high resistance. At a time equal to one-tenth RC the condenser voltage will have increased ten per cent of one hundred volts, or ten volts, making the total charge sixty volts. At the same time (point 'D') the resistor voltage will decrease ten volts (to ninety volts), leaving the sum of e_g and e_r still equal to the applied potential, 150 volts.

11. Now, at point 'D' the applied voltage suddenly drops back to fifty volts. But the condenser is charged to sixty volts. This would leave an output voltage (the voltage across 'R') of ten volts, negative with respect to ground. This is the condition we wish to avoid. In order to return to the zero reference, the condenser must discharge the extra ten volts very rapidly. This means that there must be provided a very short RC discharge path.

12. In Figure 2, it is seen that the cathode of the diode is connected to the upper end of 'R', and that the plate is grounded. Any output voltage which is negative with respect to ground will, obviously make the cathode of the diode negative with respect to its plate. In this condition the diode conducts, and becomes, in effect, a very low resistance. Current flowing through the diode will very rapidly discharge the condenser until its charge is again equal to the applied voltage (50 volts), and the output voltage returns to zero. Figure 4 illustrates the conditions.

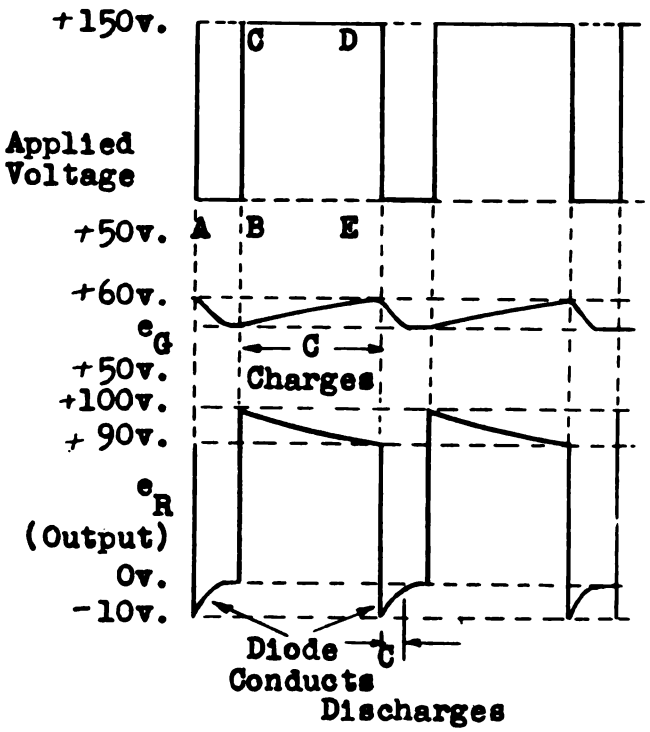

Fig. 13-4: e_c and e_r Waveforms of the Diode Clamping Circuit, with Grounded Plate, for an Input Voltage as Shown.

13. As a matter of interest, assume that the waveform of

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Figure 5, is applied to the clamping circuit of Figure 2. At point 'A' the input voltage is zero. The condenser charge at this instant (beginning of operation) is also at zero, so the output voltage is zero. At point 'B' the input and output voltage will still be zero --nothing has changed. Then the input voltage drops suddenly to -100 volts at point 'C'. Since the condenser cannot be charged instantaneously no matter how short the RC, the output voltage (voltage across 'R') must also drop suddenly to 100 volts.

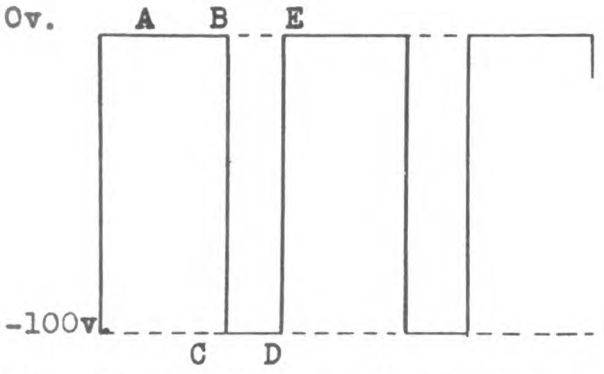

Fig. 13-5: Voltage Applied to the Diode Clamping Circuit with Grounded Plate.

14. With the cathode of the diode now 100 volts negative with respect to its plate, a very high current will flow from cathode to plate. This current will charge the condenser very rapidly until the condenser voltage becomes equal to the applied voltage, at which time the output voltage will again be zero. So long as the input voltage remains at -100 volts (point 'C' to point 'D') the output voltage (after the condenser has become charged) will remain at zero.

15. At point 'D' the input voltage rises back to zero, an increase of one hundred volts (-100 to 0) at the input. This means a rise of one hundred volts (0 to 100) across R (see point "D-E" of Figure 6), since the condenser cannot change its charge instantaneously. The condenser must now discharge very slowly since the diode is cutoff when its cathode is positive with respect to its plate, and the high resistance path through R must be utilized.

16. Assuming a time for discharge (point 'E' to point 'F') of one-tenth RC, the condenser can discharge only one-tenth of its stored energy, so at point 'F' the condenser voltage (and thus the output voltage, since the input is now zero) has decreased to ninety volts. Now the input voltage again drops ('F' to 'G') to -100 volts. Instantaneously the output voltage will be -10 volts (input minus condenser voltage). Again the diode will conduct quickly returning the charge on the condenser to one hundred volts and the output to zero. The result is shown in Figure 6. Observe that no portion of the waveform is lost after the first cycle. The function of the clamping circuit has been merely to shift the reference voltage from the top of the waveform to the bottom.

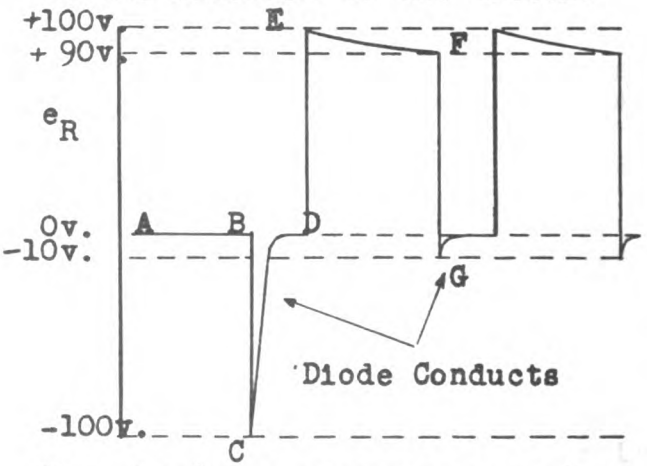

Fig. 13-6: Output Waveform (e_r) of a Diode Clamping Circuit with Grounded Plate for an Input Voltage as shown in Figure 5.

17. Figure 7 illustrates a

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diode clamping circuit which will cause the output waveform to vary between some negative value and the zero reference voltage. The only difference between this circuit and the circuit of Figure 2 is that the diode connections are reversed. For this clamping circuit the plate of the diode is connected to the output terminal, while the cathode is grounded. This arrangement will give an output voltage varying between zero and some negative value.

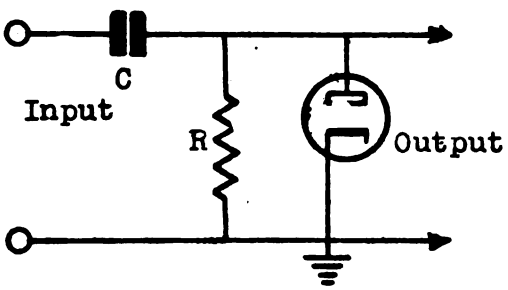

Fig. 13-7: Diode Clamping Circuit With Cathode Grounded.

18. Assume that the same wave form shown in Figure 3 is applied to this clamping circuit. When the input voltage is applied, at point 'A' the plate of the diode clamping tube will be made positive. A heavy current will flow through the diode, charging condenser 'C' very rapidly to the applied voltage (50v). When this occurs, the output voltage will drop back to zero. Then at point 'B' the input voltage suddenly rises 100 volts. Since the condenser voltage cannot change instantaneously, the output voltage must also rise 100 volts. However, with the diode plate highly positive the condenser can charge very rapidly, again returning the output voltage to zero.

19. At point 'D' the input voltage suddenly drops 100 volts. Condenser 'C' is charged now to 150 volts. It cannot change its charge instantaneously so the output must also drop 100 volts. The input voltage dropped from +150 volts to +50 volts; the output voltage must drop from zero to -100 volts. Now, during the time from point 'E' to point 'F' the condenser can be expected to discharge a little through resistor 'R'. At point 'G' this slight loss in charge will be replenished as the diode plate goes positive monentarily. The output is shown in Figure 8.

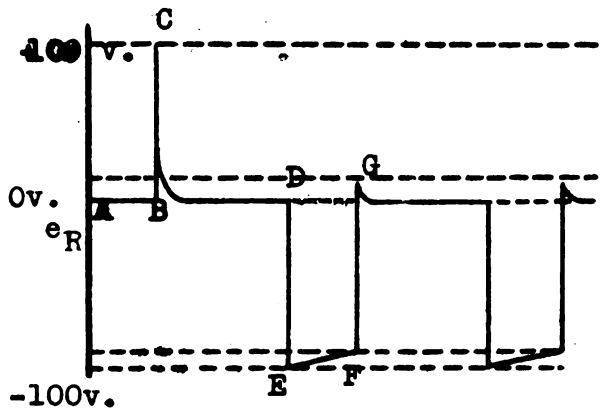

Fig. 13-8: Output Waveform (e_r) of Diode Clamping Circuit With Grounded Cathode For an Input Voltage As Shown in Figure 3.

GRID CLAMPING

20. Clamping is not confined to the use of a diode tube. The action may be present at the grid of an ordinary triode or pentode. Any element of a vacuum tube, if made positive with respect to the cathode, will draw electrons from the cathode.

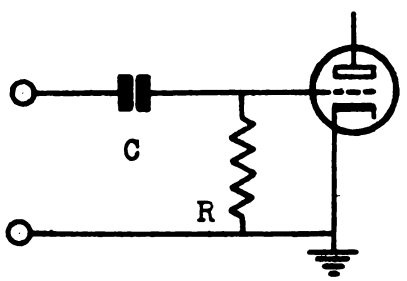

Fig. 13-9: Grid Clamping Circuit.

On the other hand, any element,

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if made negative with respect to the cathode, will repel electrons, and no current will flow to that element. Thus the grid of a tube, connected as shown in Figure 9, will act as a diode plate and give the same clamping action as the circuit of Figure 6. Any tendency for the grid to go positive will cause grid current to flow, charging the coupling condenser to the applied potential.

CLAMPING ABOVE OR BELOW GROUND POTENTIAL

21. So far, the circuits shown have served the purpose of clamping one extreme of the output waveform to zero, or ground, potential. Actual circuits need not be limited to this one reference potential. Figure 10 shows how the upper extreme of a waveform may be clamped to a potential ten volts negative with respect to ground. Exactly the same principle may be used to clamp either extreme to any reference potential.

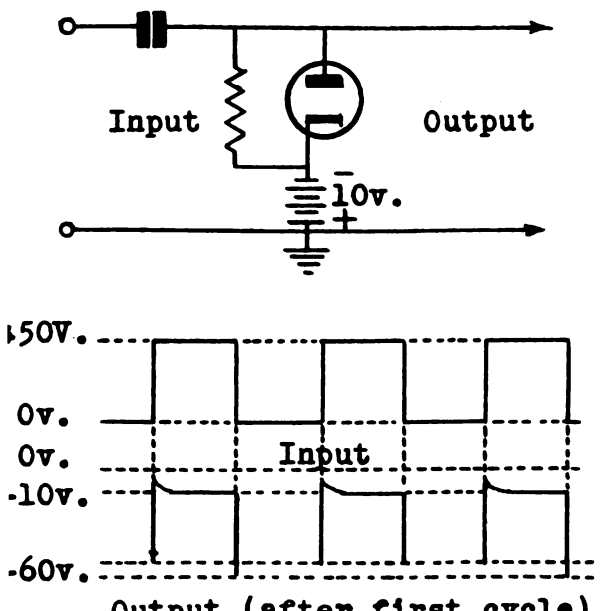

Fig. 13-10: Clamping Circuit Which Establishes a minus 10 Volt Reference Potential.

22. A more versatile clamping circuit is shown in Figure 11.

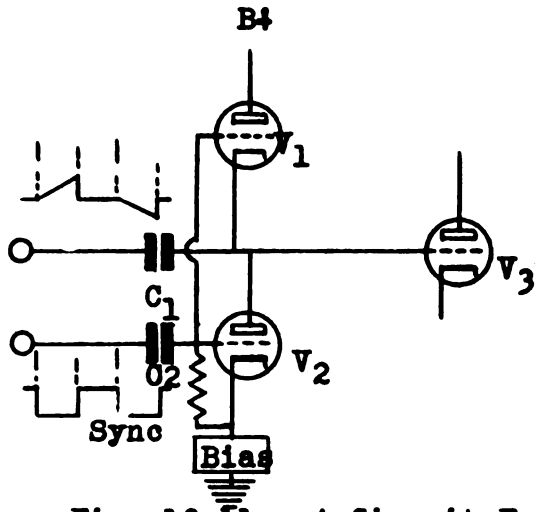

Fig. 13-11: A Circuit Employing Synchronized Clamping.

This arrangement keeps the bias on V_3 constant except for the time during which the clamping tubes, V_1 and V_2, are maintained beyond cut-off by a synchronizing pulse. First, consider the action of the circuit during the time tubes V_1 and V_2 may be considered together as a voltage divider to place a definite voltage on the grid of V_3. Actually, the action is slightly more complicated, and much more accurate than the simple voltage divider explanation would imply.

23. An examination of Figure 11 will show that while V_2 is operating at zero bias (grid to cathode) and may therefore be considered as a simple resistor, V_1 is actually biased by the drop across V_2. (The cathode of V_1 is connected directly to the plate of V_2, while the grid of V_1 is connected to the grid of V_2 which in turn, is effectively connected to the cathode of V_2 so long as no synchronizing potential is applied). Now consider how this connection serves to maintain a constant potential at the grid of V_3.

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24. Assume that for some reason (perhaps a charge on C_1) the potential at V_3 tried to rise. Neglecting the fixed bias, since it will not change, the voltage at the grid of V_3 and the voltage across V_2 are identical. Thus a rise in V_3 grid voltage will also be a rise in V_2 plate voltage means an increase in the bias of V_1, which will decrease its plate current and bring the voltage at the plate of V_2 back to normal.

25. In like manner, a decrease in the voltage at the grid of V_3 will mean a decrease in bias of V_1, which will increase the current through V_1, and thus bring the voltage at V_3 back to normal. So long as tubes V_1 and V_2 conduct, the voltage at the grid of V_3 (and thus the plate current of V_3) is held constant.

26. The synchronizing pulse is applied as a negative square wave which drives V_1 and V_2 beyond cut-off for the desired length of time. With tubes V_1 and V_2 cut-off, the grid of V_3 is left absolutely free to follow any changes in the input voltage. Condenser 'C' will have no path through which to charge or discharge - except for the extremely high resistance of the insulating material used for tube bases and sockets--so the voltage at the grid of V_3 must follow the input voltage exactly. At the end of the synchronizing pulse tubes V_1 and V_2 will again conduct, returning the voltage at the grid of V_3 quickly to reference level.

GENERAL APPLICATION OF CLAMPING CIRCUITS

27. So far in this chapter, only the actual operating principles of various types of clamping circuits have been discussed. It would be well at this point to review their practical applications.

28. In practice, clamping is usually encountered in sweep circuits. The necessity for a clamping circuit can be seen immediately by referring to an indicator using a type 'A' or a type 'Z' scan. If the sweep voltages do not always start from the same value of voltage, it is obvious that the trace itself will not begin at the same point on the screen each time, thereby resulting in a trace which is 'jittery' or erratic. If a clamping circuit is placed between the final sweep amplifier and the deflection plate the voltage from which the sweep signal will start can be fixed by adjusting the DC voltage applied to the clamping circuit. An arrangement, such as that shown in Figure 10, will assure, in the case of a negative-going sweep voltage, that the waveform applied to the deflection plate will vary in a negative direction from the DC voltage level applied to the cathode of the diode.

29. A magnetically deflected cathode ray tube offers another instance of sweep clamping in the use of a diode in the grid circuit of the final sweep amplifier. Such a circuit is shown in Figure 12. This arrangement assures that the negative extreme of the sweep waveform will always be clamped at the DC level of -60 volts. This means that the static current, which at the beginning of the sweep, will be flowing in the final sweep amplifier tube and in the deflection coil, will always be the same value - since the biasing voltage on the grid at that time is always the same value. Therefore, the beam will always start its trace from the same spot on the screen because the static current in the coil at the beginning of the trace determines the position of that spot. This clamping

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circuit, when applied to a type 'P' scan sweep circuit, is often called a "centering diode".

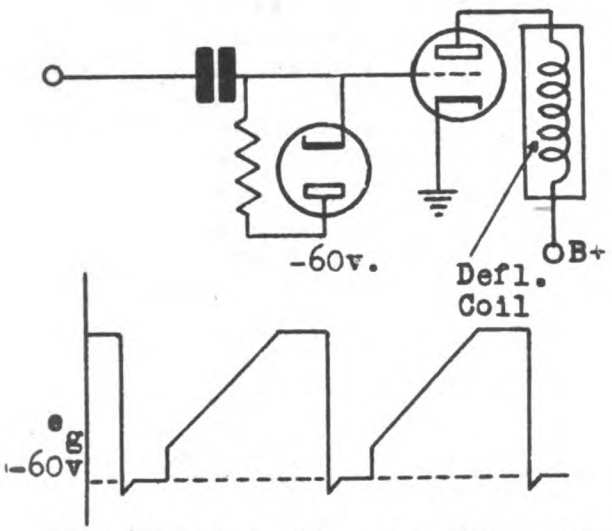

Fig.13-12: Clamping Diode Employed in An Electromagnetic Sweep System.

30. It is necessary in a type 'L' scan to produce amplitude modulation of the sweep or trace so that, for a short period of time, signals cause deflection on one side of the trace and then similarly other signals cause deflection on the opposite side of the trace. (See definition of type 'L' scan in Appendix A). If these signals are applied to the deflecting plates of a cathode ray tube without going through a clamping arrangement of some type, they will merely vary about the trace instead of appearing as deflections entirely on one side or the other. If the signals are applied to a clamping circuit, they are clamped to a DC level; they become voltage variations above a fixed voltage or below a fixed voltage, as the case may be. This assures that the signals, when applied to the deflection plates, will always cause deflection in one direction only, with respect to the trace. By making variable the voltages to which the amplitude extremes of the signals are clamped, it is possible in conjunction with the control obtained when sweep clamping circuits are also used to move the trace to the part of the tube screen best suited for viewing.

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CHAPTER XIV

Electrostatic Sweep Generation

1. The use of a Radar indicator as a time measuring device requires that a sweep generating circuit be employed. The latter applies voltage or current to the deflection elements of the cathode ray tube in such a manner as to make the rate of deflection of the electron beam a known function of time. Against this time base other periodically occurring electrical phenomena may be plotted and measured. Before proceeding further the properties of the cathode ray tube will be discussed briefly.

2. The Electron in an Electrostatic Field: An electron (being a negative charged particle) will, upon subjection to an electrostatic field, be either attracted or repelled, depending upon the polarity of that field. In other words, if the electron enters a field which is negative, it will be repelled (since like charges repel each other) but, if the electron enters a positive field, it will be attracted. When an electron is traveling at considerable velocity and it encounters an electrostatic field whose lines of force are not parallel to its line of motion, the electron will alter its forward motion in an attempt to move parallel to the electrostatic lines of force. The operation of an electrostatic cathode ray tube depends upon these principles.

3. The Electron Gun: Electron beams are formed in a structure known as an "electron gun". The latter is devised so as to form a beam and to focus it on the screen of a cathode ray tube. The gun in an electrostatic type tube will be discussed in this chapter.

4. A typical example of an electrostatic gun is shown in Figure 1.

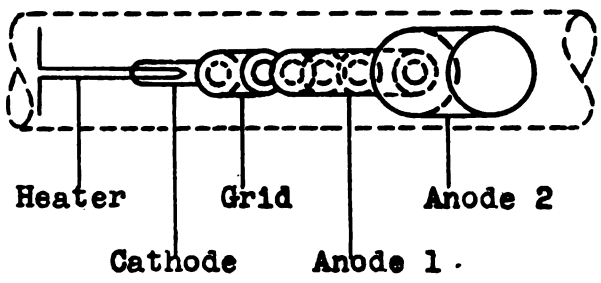

Fig. 14-1: An Electron Gun.

At the extreme left in the diagram is the cathode, consisting of a capped nickel sleeve. Within this sleeve is the heater used to bring the cathode surface up to operating temperature. The cathode cap is covered with barium and strontium oxides, a mixture which is capable of emitting electrons when heated.

5. Next to the cathode is the control grid, made up of a capped nickel sleeve. This cap contains a small aperture, through which must pass any electrons that travel through the grid. Such electrons are necessarily confined to a narrow cone.

6. To the right of the control grid and insulated from it is a cylindrical sleeve containing several apertures placed at intervals on the axis of the system. These apertures serve to confine the beam further. The first anode is maintained at a

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potential which is positive with respect to the cathode and thereby attracts electrons from the cathode through the several apertures.

7. Beyond the first anode is the second anode, which may be simply a conducting coating inside the glass envelope surrounding the gun. The second anode has a larger diameter than the first and is placed so that its edge just overlaps it. The second anode is maintained at a considerably higher positive potential, with respect to the cathode, than is the first.

8. The Cathode Ray Tube: When such an electron gun is placed in a tube that has a flourescent screen, the unit becomes a cathode ray tube, and as such can be used to observe visually the periodic variations of voltages occurring in electrical circuits. However, before the electron gun will cause a narrow beam of electrons to be "shot" at the screen, the correct voltages must be placed on the various parts of the gun. By varying the voltage on the grid of the gun, the intensity of the beam (or brilliance) can be controlled. By varying the potential on the first anode the beam can be focused into a very narrow pencil that will appear on the screen as a small, well defined spot.

9. Brilliance Control: The brightness of the spot which appears on the cathode ray tube screen is a function of the number of electrons making up the beam. Consequently, it should be possible to control the brightness of the image simply by regulating the number of electrons that are allowed to get past the grid. By keeping the grid potential negative with respect to the cathode, and making it variable, the number of electrons which pass through the grid and eventually hit the screen can be controlled.

10. Electrostatic Focusing: An electron lens can be formed by means of two metal cylinders connected to a source so that the second is at a potential which is positive with respect to the first. When a parallel bundle of electrons, traveling at a constant velocity, as in Figure 2, enters the electrostatic field between the ends of the cylinders, it is converged toward a point (O in the figure) because the electrons must assume a compromise motion between their forward paths and the direction of the electrostatic lines of force.

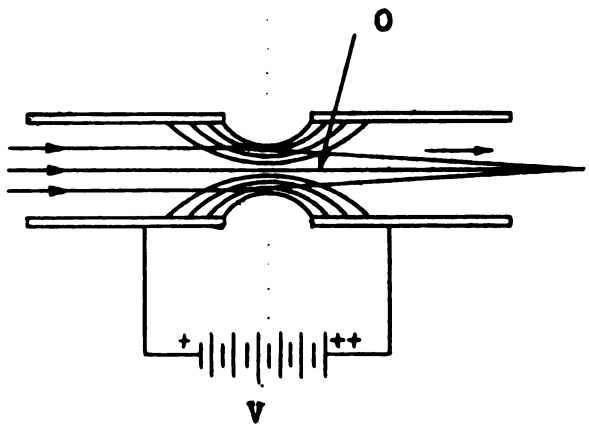

Fig. 14-2: A Double-cylinder Lens.

After passing the gap between the two cylinders, the electrons find themselves in an electrostatic field which tends to cause them to diverge, or spread out, again. But, at this point, the electrons are traveling faster, having been accelerated across the gap by voltage V. Hence they continue down the cylinder, converging toward a more distant point.

11. In Figure 3, the second cylinder is larger than the first cylinder, as might be the case when the second anode is the conductive coating on the inside

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of the glass envelope. This means that the electrostatic field in this region is weaker and its divergent action on the electrons is less. Hence the electrons come to a focus sooner than in the case where the two cylinders are of the same diameter.

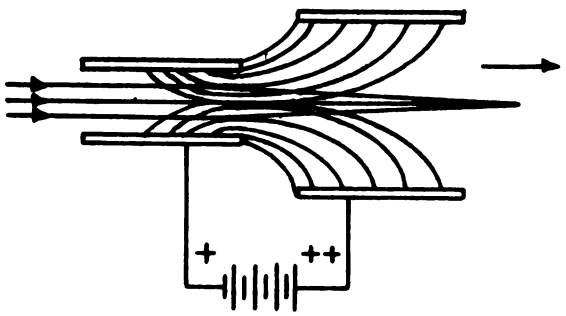

Fig. 14-3: A Short-Focus Double-cylinder Lens.

12. Potentials Applied to Electron Gun: In Figure 4 an electron gun is shown with voltages applied to the various elements, which might be representative of any cathode ray tube circuit.

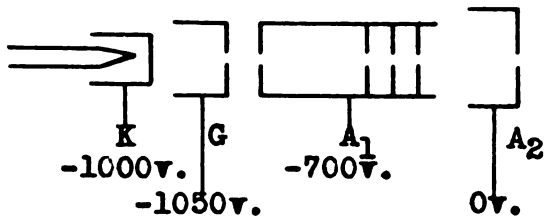

Fig. 14-4: Potentials Applied to an Electron Gun.

Higher voltages, if used, will increase the velocity of the electron beam causing an increase in brilliance. The ratio of the voltages in this particular case, however, will apply to practically all tubes. As can be seen from the diagram, the cathode is actually operated at a highly negative potential, 1000 volts with respect to ground. This is the same as placing the accelerating anodes at a high positive potential, since the difference in potential would remain the same. The grid voltage is placed at -1050 volts and is made variable, so that more or less beam current passes through the gun to the screen. The first anode has a potential of -700 volts applied to it, so that it is actually 300 volts positive with respect to the cathode. The second anode has 0 volts applied to it. This means that there is 700 volts difference in potential between the first or focusing anode and the second anode. The electrons passing through this part of the gun will experience converging motion as well as an acceleration. The focusing anode is connected to a potentiometer so that the voltage on it can be varied either side of -700 volts to obtain the proper degree of focus.

13. Function of the Deflection Plates: When considering the function of the deflection plates in a cathode ray tube, it is necessary to remember several facts already mentioned in the discussion on focusing, but which also apply to the principle of deflection. One is that electrons are particles of electricity, bearing a negative charge at all times. Another fact is that electrons are repelled by a negative field of any medium, attracted by a positive field. Still another is that the electrons which pass through the deflecting fields are in a narrow stream of beam.

14. The position of the beam, after it has left the electron gun, with no voltages applied to the deflecting plates, is midway between the plates which should place the spot in the center of the viewing screen.

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In the cathode ray tube of Figure 5, two sets of plates are shown. If a voltage is applied to a pair of these plates, so that one is positive while the other is negative, the beam will be deflected from its central position in the direction of the positive plate. As seen on the fluorescent screen, the spot of light is moved to a new position away from the center. When an alternating potential is applied to the deflection plates, the electrons are alternately deflected back and forth to produce a line of light on the screen.

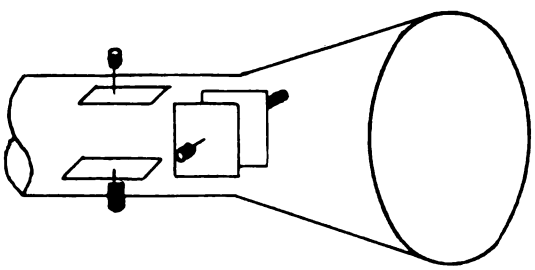

Fig. 14-5: Deflection Plates of a Cathode Ray Tube.

15. Thus is provided a means of studying changes of voltage or current with time. If some method can be devised to apply linear changes in voltage to one set of deflection plates, then periodically recurring signals can be seen on the screen of the tube as amplitude variations of that sweep when the signal voltages are applied to the other set of deflection plates. In the following paragraphs several methods of obtaining such voltage changes are discussed.

GAS TUBE RELAXATION OSCILLATOR

16. The simplest form of sweep generator is the relaxation oscillator, using a glow-discharge tube in conjunction with a resistor, condenser, and a DC voltage source. This is shown in the schematic in Figure 6.

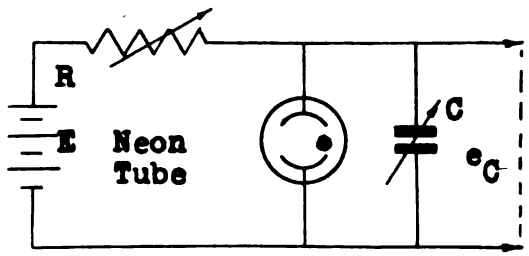

Fig. 14-6: Neon Tube Relaxation Oscillator.

The oscillator portion of the circuit consists of the DC voltage source, condenser C, and the glow tube (a common neon or argon tube). In the circuit shown, the discharge tube is connected across the frequency controlling condenser. The resistor R, being variable, can also be used to control frequency, but for the sake of illustration, this unit is considered as being fixed in value.

17. Operation of the device is along the following lines: Current from the DC voltage source flows through the resistor, charging the condenser to a certain voltage. Normally, were it not for the presence of the glow discharge tube, the condenser would charge to the full value of the DC voltage, but with the tube connected across the condenser, this does not occur; when the voltage across the two anodes of the tube reaches a certain value, the gas ionizes; the tube flashes and becomes a conductor. When this happens, the tube short-circuits the condenser and dissipates its charge.

18. It is characteristic of such gas-filled tubes that once ionization has occurred, it will persist even if the voltage

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across the tube electrodes is somewhat reduced. However, when the voltage across the tube anodes reaches the lower critical value, ionization ceases and the tube again becomes a non-conductor, and the condenser charging cycle starts all over again. Thus the tube can be said to have two critical values of voltage; namely, an ionizing and a de-ionizing potential.

19. The usual arrangement is to use a glow-discharge tube that has a breakdown voltage rating appreciably lower than the voltage of the supply. Suppose, by way of illustration, that a tube having a critical ionizing voltage of 60 volts is used with a 100 volt supply. When, during the initial charge cycle, the voltage across the condenser reaches 60 volts, the tube ionizes and the condenser is discharged through the tube. The voltage across the condenser falls to a value less than that required to keep the gas within the tube in a state of ionization, the tube again becomes a very high resistance, and the condenser recommences its charging cycle.

20. When a system of this type is used to supply the sweep voltage, or time base, the charging voltage developed across the condenser is used as the potential which sweeps the beam spot across the screen, and the discharge cycle is the voltage which returns the spot to its initial starting position. Figure 7 shows several cycles of the output voltage waveform of the neon tube oscillator illustrated in Figure 6. The sloping line which rises from zero to maximum can be considered as the charging cycle, since it indicates the rise in voltage across the condenser. The discharge trace is the steep drop from maximum to de-ionization; it is barely visible on an oscilloscope, because the spot is swept across the screen so rapidly that it does not receive enough energy to make it fluoresce noticeably.

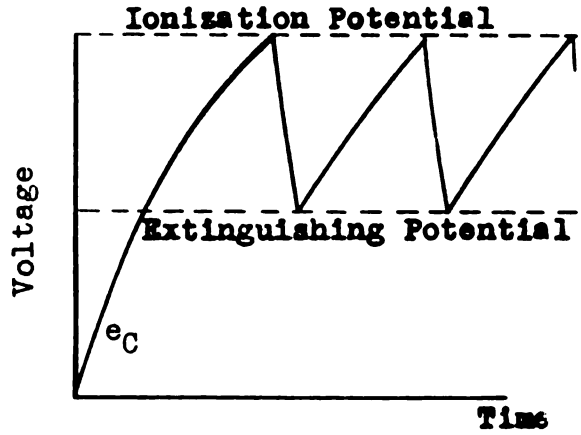

Fig. 14-7: Output from Neon Tube Sweep Generator.

21. The frequency of a relaxation oscillator of this type can be varied in three ways: With the flashing voltage and the resistance constant, variation of the capacity will vary the frequency. With capacity and flashing voltage constant, variation of the resistance will vary the frequency. Increasing the capacity, increases the time required for the voltage to build up across the condenser; so that in a given period of time fewer charging cycles occur than would be the case with a smaller capacity, since the latter would require less time to become charged to the flashing voltage. By the same token, raising the resistance increases the time required for the capacity to become charged to a certain voltage. These conditions apply to all types of relaxation oscillators, since frequency is a direct function of the charging or discharging time or resistance-capacity combinations. If the flashing voltage is reduced, it will require less time to develop this potential across the condenser, which again means that the frequency will be higher.

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THYRATRON SWEEP GENERATOR

22. Operation: The thyratron sweep generator functions in much the same manner as the neon tube relaxation oscillator. A thyratron is a triode filled with an inert gas (usually argon) which will ionize when the voltage between the cathode and the plate reaches a certain value. The voltage at which ionization occurs depends upon the bias applied to the grid. In other words, the flash voltage is a function of the grid voltage. With a given negative bias applied to the control grid, the tube will flash at a certain plate voltage. This potential may be developed across a condenser connecting plate and cathode to ground. As the flashing potential is reached and the grid loses its control the condenser discharges through the tube. When the voltage across the condenser is reduced to the lower critical potential, the tube deionizes, whereupon the grid again takes control; the tube becomes a non-conductor, and the charging cycle starts all over. The potentiometer P, Figure 8, is used solely to establish the proper flash voltage to produce the most linear sweep possible.

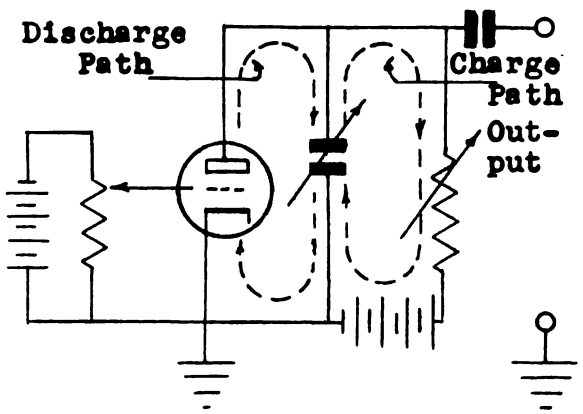

Fig.14-8: Thyratron Sweep Generator.

23. The thyratron sweep generator can be made to operate with an external synchronization signal. By applying an appropriate voltage to the grid of the thyratron the sweep frequency may be "locked in step" with the frequency of the signal being observed. This is done by feeding a small portion of the voltage to be observed (i.e., the voltage applied to the signal plates of the CRT) to the input circuit of the time base tube. The pulses will maintain the frequency of the sweep generator at the setting required for developing the proper image. The sweep generator will keep step with these synchronizing pulses, whether they are a multiple or a sub-multiple of the frequency of the sweep oscillator. This locks the image in a stationary position on the screen of the CRT.

HARD TUBE SWEEP GENERATOR

24. In the neon tube and thyratron types of sweep generators, the frequency of the sweep is entirely dependent upon the constants of the circuits. In Radar equipment there is need for a sweep generator whose frequency can be synchronized with an external pulse generator, such as a blocking oscillator or multivibrator. In the case of blocking oscillators, the need for this can be seen as a complete sweep must occur for each pulse of the oscillator. If a blocking oscillator is used to trigger the sweep generator, the two circuits must of necessity be synchronized at the same frequency. Likewise, if a multivibrator is

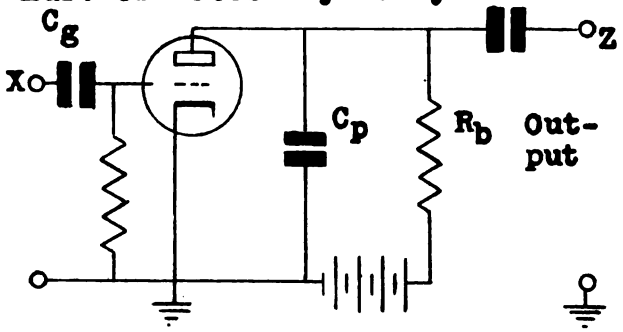

Fig.14-9: Hard Tube Sweep Generator.

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used to trigger both the blocking oscillator and the sweep generator this is true. In Figure 9, is shown a convenient circuit that can be triggered externally to produce a sweep which meets the above requirements. It is known as a vacuum or hard tube sweep generator.

25. In this circuit synchronization pulses are applied to the grid circuit, output being taken from the plate circuit. By way of analysis, assume that a waveform as shown in Figure 10(a) is used to trigger the circuit into operation. This waveform may be obtained from a multivibrator, since this device is capable of producing very reliable rectangular waves.

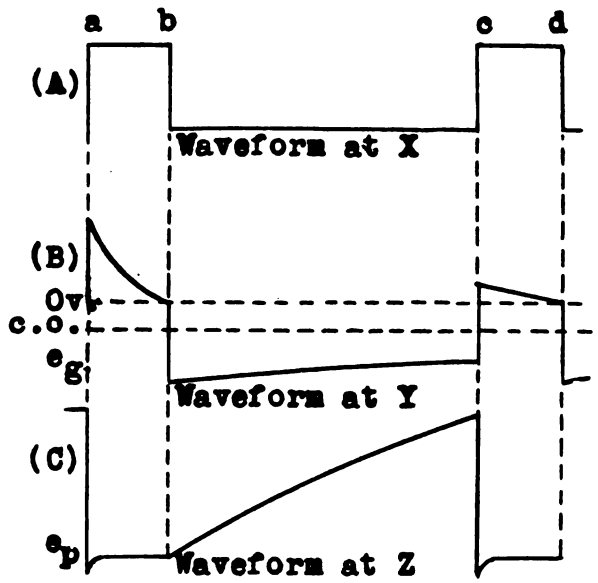

Fig. 14-10: Waveforms of a Hard Tube Sweep Generator.

26. As the leading edge (a) of the positive-going square wave is applied to the input circuit, the grid is driven very positive so that grid current flows, quickly charging up the grid condenser through the low resistance between grid and cathode. This action can be followed in Figure 10(b). Then as the trailing edge (b) of the positive pulse is applied, the grid is driven very negative, cutting off the tube. The charge on the condenser in the grid circuit will now attempt to leak off through the grid resistor; but, since this is a large resistance, the resultant time constant will be so long that the charge will have only partially leaked off when the next positive pulse (point c) is applied. Therefore, the grid will be driven only slightly positive just enough to replenish the charge that leaks off between pulses.

27. In the plate circuit the changes which occur simultaneously should now be investigated with the grid action. With zero volts on the grid, or with the tube in a static condition, the voltage at the plate will be at some steady value. As the grid voltage rises (Figure 10(B), point a) the plate current will increase, causing the plate voltage to drop. This action can be followed in Figure 10(C). As the grid voltage is increased, the resistance of the tube drops to a low value and the condenser in the plate circuit is discharged through the tube. This operation is very similar to the discharging of the condenser in the neon tube and thyratron sweep generators. When, at point b, the voltage on the grid is suddenly swung in a negative direction, the tube is cut-off. Since the tube resistance is now infinitely high, the condenser will not continue its discharge. Furthermore, the charge across it is now less than the applied potential; consequently, it will start to charge through the resistance in the plate circuit. If only the most linear portion of the charging curve is used a good sweep waveform can be obtained. If the grid voltage does not rise enough to allow the tube to conduct before the next pulse, the sweep voltage will be equal in time duration

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to the time between the trailing edge of one pulse and the leading edge of the next pulse. If the tube does become conductive before the next pulse occurs, the condenser will begin to lose its charge sooner, thus decreasing the sweep time. This is shown in Figure 11.

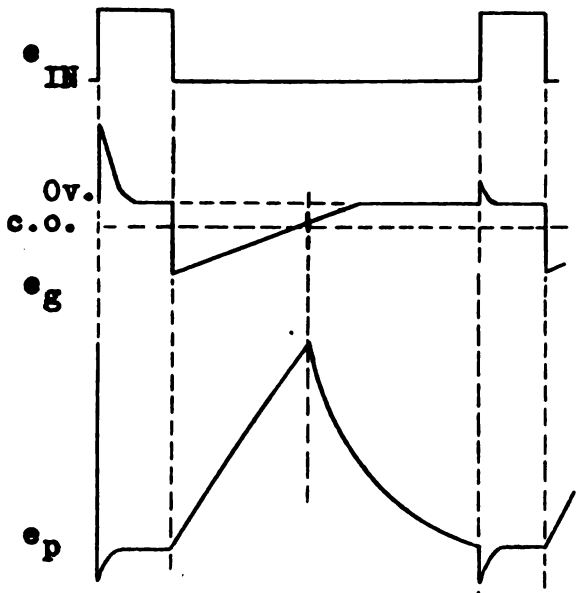

Fig. 14-11: Resultant Waveforms When Grid Rises Above Cutoff Before Next Input Pulse.

28. On succeeding pulses the same action will occur as on the first pulse, except that the grid will not be driven to such a positive value, even momentarily, as it was on the first cycle before the grid condenser became charged.

29. Determination of Sweep Time: It is possible to control roughly the length of the sweep time by causing the grid voltage waveform (Figure 11) to reach cutoff in a longer or shorter period of time. This can be done by changing the RC time constant in the grid circuit, so that more or less time is required for the grid condenser to discharge to cutoff. The same effect can be produced by applying a positive voltage to the grid resistance, so that the condenser will attempt to discharge to zero and then charge to the voltage applied. This will cause the cutoff point to be reached more rapidly as the condenser discharges than if the condenser had only the voltage across itself to discharge.

30. The time of the sweep may be controlled further by use of a limiting circuit. Diode, grid, or plate-limiting would be effective, but usually diode or grid-limiting is employed. This circuit limits the amplitude and decreases the time simultaneously. The block diagram for such a system is shown in Figure 12.

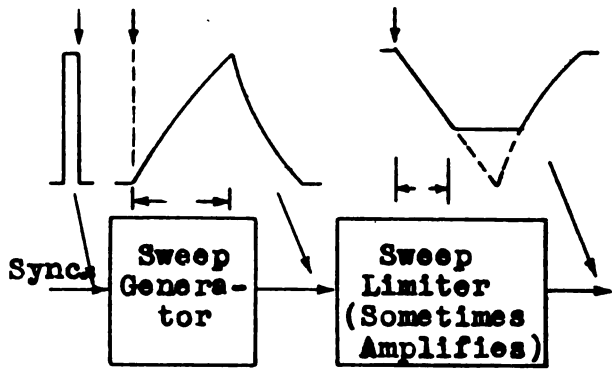

Fig. 14-12: Block Diagram of Limiter for Generator used to Adjust Time Duration of Sweep.

31. If the sweep is linear, and its time duration can be controlled, it is possible to construct a scale which may be calibrated in microseconds and superimposed on the trace on the screen of a cathode ray tube. With such a scale on the tube it would be possible to note the time difference in microseconds between the pulse which synchronizes the sweep generator and any other signal also synchronized with that pulse, but occurring at a later time.

32. This is precisely what is done in Radar. For conven-

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ience in calibration the scale is marked in miles or yards instead of microseconds, which is permissible since distance is a function of time. Range marker pips to be discussed in chapter XVIII, can be used to calibrate the screen since the period of time between successive pips is also a function of time. The reflected signal or echo can easily be ranged, therefore, by superimposing it on the sweep and noting the difference between its position and the start of the trace.

33. In order to obtain a longer sweep and still keep linearity, the time constant of the charge path of the sweep generator must be lengthened. In Figure 13, waveforms are shown that might be applicable to the schematic in Figure 9. In (B) the duration of the linear portion or the charging voltage is relatively short compared to the period between synchronizing pulses.

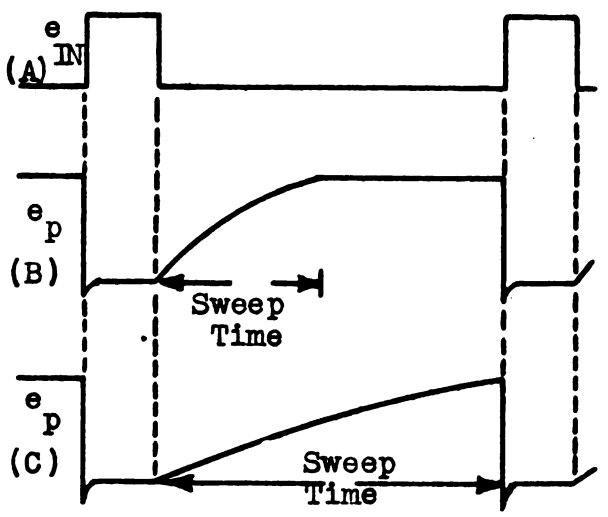

Fig. 14-13: Effect of Short and Long RC constant in Sweep Generator.

This then would be the type of waveform to be used for a short range. In (C) the time constant of the charging path is longer, so that the linear rise in voltage across the condenser lasts for a longer period of time; consequently a signal may be ranged, even though its distance as a function of time is such that it occurs almost at the end of the period between pulses.

34. Push-Pull Deflection: The waveforms which have been discussed throughout this chapter may be applied to one deflection plate in a cathode ray tube, while the other is held at a constant voltage, to obtain deflection of the beam of electrons. But in order to obtain a trace which is more linear, it is desirable to use an arrangement whereby sweep waveforms of opposite polarity can be applied to the two deflection plates. This may be accomplished by feeding a sweep waveform directly to one deflection plate and applying it simultaneously to a phase inverter which reverses the polarity of the signal without changing its amplitude. (See chapter XV) The output of the phase inverter is then connected to the other deflection plate, so that as one plate goes positive, attracting the electron beam, the other plate goes negative, repelling it.

INDICATOR GATE

35. It is desirable to have the cathode ray tube inoperative during that part of the period between synchronizing pulses when there is no need for a trace. This inoperative condition may result from a high bias between grid and cathode of the tube, so that the grid must be driven in a positive direction (or the cathode in a negative direction) in order for beam current to flow. This means that a pulse equal in time duration to the trace must be applied to the proper element of the electron gun. The circuit which is used to accomplish the sensitizing of the tube is call-

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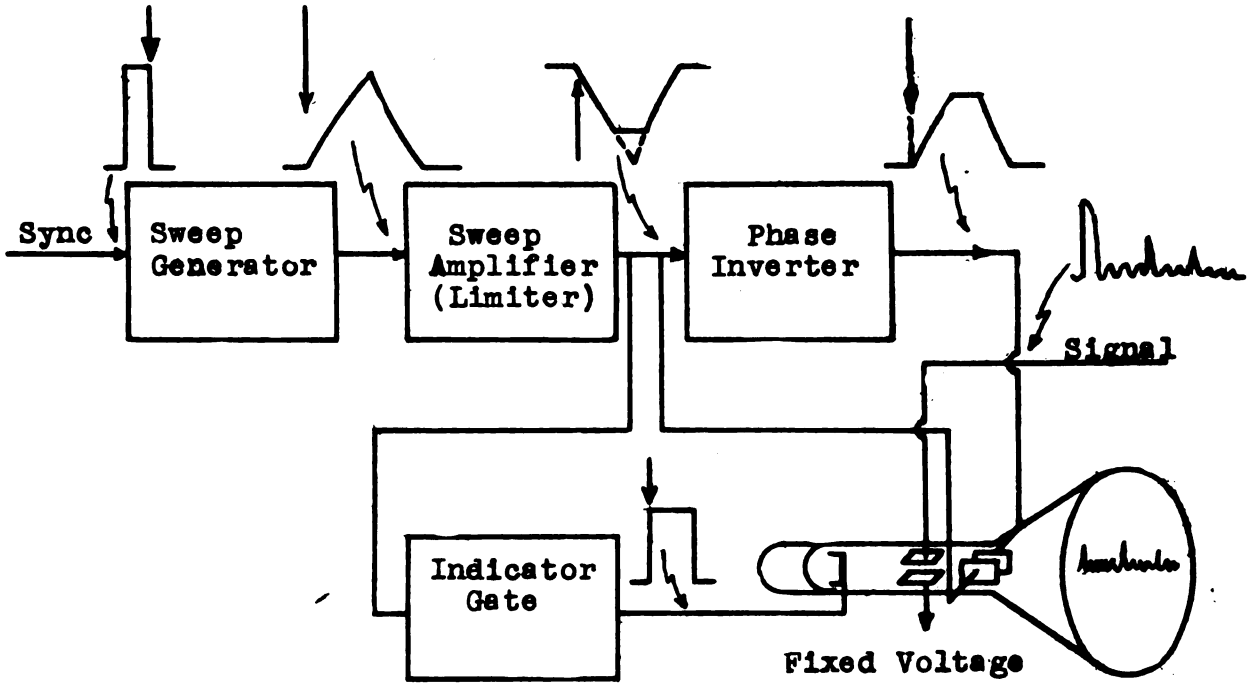
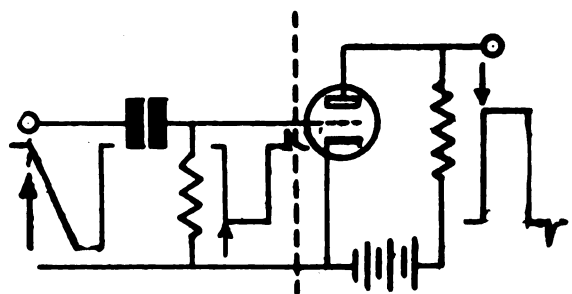


Fig. 14-14: Block Diagram of a Simple Indicator.

ed an "indicator gate". Figure 14 shows a block diagram of a simple indicator which contains the circuits just discussed.

36. It will be recalled, (chapter III) that a sawtooth voltage waveform applied to a short RC differentiator circuit results in a square wave output. See Figure 3-15. If the negative-going output of the sweep limiter-amplifier of Fig-14 is applied to an indicator gate circuit, composed of an RC differentiator--amplifier, the negative-going sweep will be differantiated and applied to the grid of the amplifier. The amplifier output, a positive-going square wave with a time-duration equal to the sweep time, may then be applied to the grid of the CRT, removing the bias and allowing the tube to conduct for the sweep-time only.



Differentiator Amplifier

Fig. 14-15: An Indicator Gate Circuit Employing a Differentiator-Amplifier.

37. With the grid of the CRT held well beyond cutoff except during the sweep-time there is no visible retrace. Likewise, echos returning from ranges greater than the sweep-range will not appear "piled up" at the end of the trace.

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CHAPTER XV

Phase Inverters

1. A Phase Inverter is an amplifier employing degeneration and, in some instances, a voltage divider network in its grid circuit to invert the polarity of a signal without changing its amplitude. There are instances in Radar circuits where a waveform of the desired shape and amplitude has been developed but which is of the wrong polarity for the particular application under consideration. Some type of phase inverter circuit for changing the polarity of the waveform without changing its amplitude or distorting its shape is required.

2. Other applications require two input signals of opposite polarity. A single input waveform of the desired shape is available but of insufficient amplitude. It must be amplified and converted to a push-pull output. An amplifier fulfilling these requirements is commonly called a Paraphase Amplifier, or Phase Splitter. Sometimes a transformer will meet these specifications if it is provided with a center-tapped secondary or with a center-tapped resistance across the secondary.

3. It should be pointed out that the commonly accepted term, "Phase Inverter" is something of a misnomer since phase is ordinarily associated with time and there is no appreciable time difference or phase shift between the input and output circuits of the ordinary phase inverter. It is only an "apparent" phase inverter, but is in reality a polarity inverter. This should be borne in mind whenever the term "Phase Inverter" is used.

TRANSFORMER AS A PHASE INVERTER

4. The output waveform at the plate of the tube in Figure 1 has a positive polarity with respect to the reference level indicated.

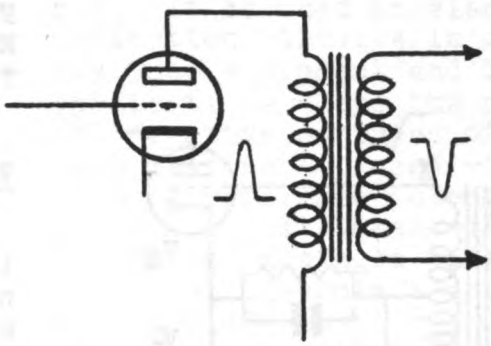

Fig. 15-1: A Transformer Performs Polarity Inversion.

For the purpose of illustration let it be assumed that the circuit following tube V_1 requires a negative pulse of the same shape. This requirement can be met by utilizing the polarity inverting property of an ordinary transformer. To have the same amplitude the transformer should have a turns ratio of one-to-one.

5. Now assume that instead of the single output voltage of Figure 1, two output signals of equal amplitudes and opposite polarity are required to drive a push-pull amplifier. To meet these conditions a transformer with center-tapped secondary may be employed as shown in Figure 2. With this center tap grounded, at some instant of time when the voltage at point X is going

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positive with respect to ground, the voltage at point Y will be going negative with respect to ground. Thus the voltage on the grid of V_2 will be of opposite polarity to the output of V_1 and the voltage on the grid of V_3 will be of the same polarity as the output of V_1. The output of the transformer is now divided equally or split between the grids of V_2 and V_3. This arrangement will be entirely satisfactory provided the transformer is designed to reduce distortion to the required minimum.

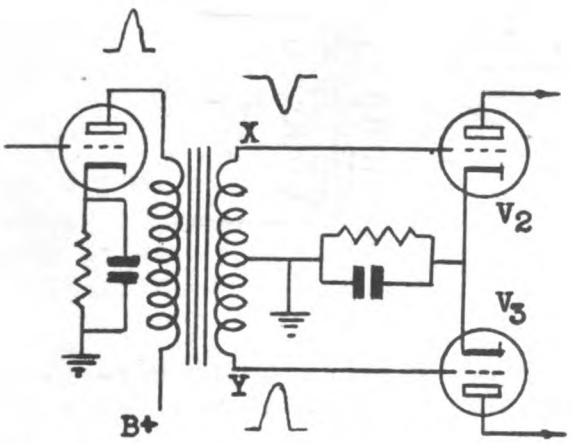

Fig. 15-2: A Center Tap Transformer Employed to Drive a Push-pull Amplifier.

6. An alternate arrangement which does not require center-tapping of the transformer secondary is shown in Figure 3. In this case an ordinary transformer with a single secondary winding is used and a resistance divider is placed across the secondary and center-tapped in order that it may be returned to ground to effect the voltage "splitting".

7. The transformer as a phase inverter or phase splitter in Radar has its limitations in that it is difficult in some cases to keep distortion to a minimum. For more critical performance specially designed amplifiers are employed.

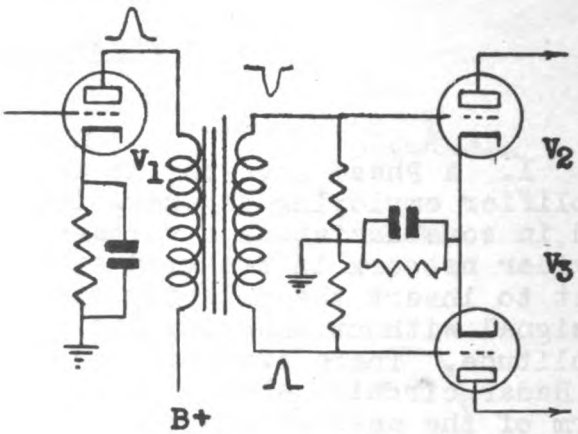

Fig. 15-3: A Voltage Divider Employed Instead of Center-Tapping the Secondary.

VACUUM TUBE AS A PHASE INVERTER

8. In some circumstances it is necessary to reverse the polarity of a pulse or waveform without changing its amplitude. Aside from the somewhat doubtful use of a transformer, this is readily accomplished by the use of an ordinary RC coupled amplifier with an unbypassed cathode resistor as shown in Figure 4.

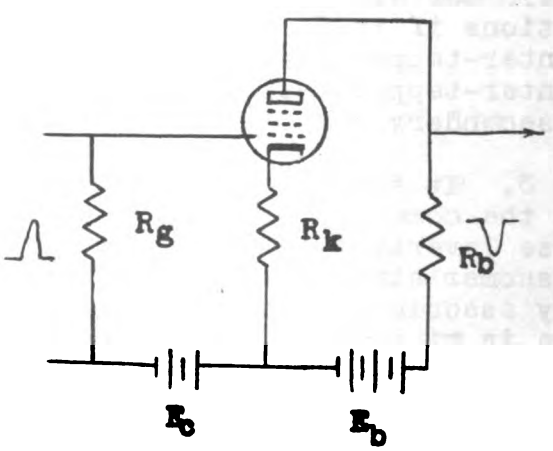

Fig. 15-4: A Phase Inverter Employing Cathode Degeneration.

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It will be recalled that any ordinary vacuum tube amplifier with a resistive load in the plate circuit is fundamentally a phase inverter with grid and plate voltages opposite in polarity. The true phase inverter circuit however, does not produce any voltage gain. It is designed to invert polarity without affecting amplitude. But since the vacuum tube is an amplifier some means of neutralizing its gain is required if there is to be no change in amplitude from input to output.

9. The most generally used method is that employed in Figure 4; degenerative (negative) feedback. This is accomplished by leaving out the usual bypass condenser across the cathode resistor. Depending upon the size of the cathode resistor, voltage gain and distortion are reduced (See chapter IV). If R_k is of the correct value the degeneration produced will be just sufficient to reduce the gain of the circuit to unity.

10. In addition to degeneration, another method of equalizing the input and output amplitude of the phase inverter is that of employing a voltage divider network in the grid circuit of the phase inverter. This is generally used together with a small amount of degeneration thus retaining its tendency to reduce distortion. See Figure 5. It is necessary to adjust the values of R_1 and R_2 making R_1 larger and R_2 smaller until the losses introduced in the grid circuit just balance the gain or the tube.

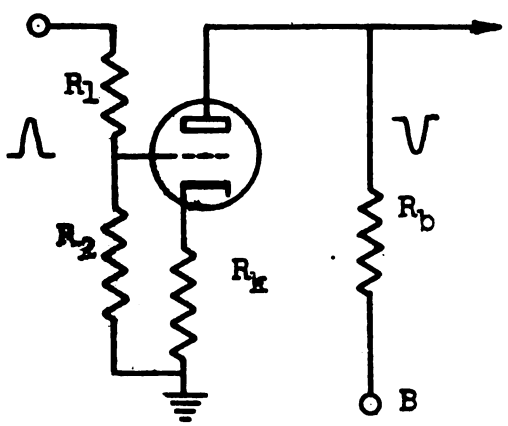

Fig. 15-5: Phase Inverter Employing a Voltage Divider Network.

PARAPHASE AMPLIFIER OR PHASE SPLITTER

11. A paraphase Amplifier is one used for converting a single input to a push-pull output. It is used in electrostatic deflection circuits in cathode ray tube equipment and in other applications where the positive and negative portions of a waveform must be balanced with respect to some reference potential, such as ground. It takes either of two forms; a single tube circuit which combines plate coupling with cathode coupling, or a two-tube circuit, in which the output of one tube is coupled to the input of the other.

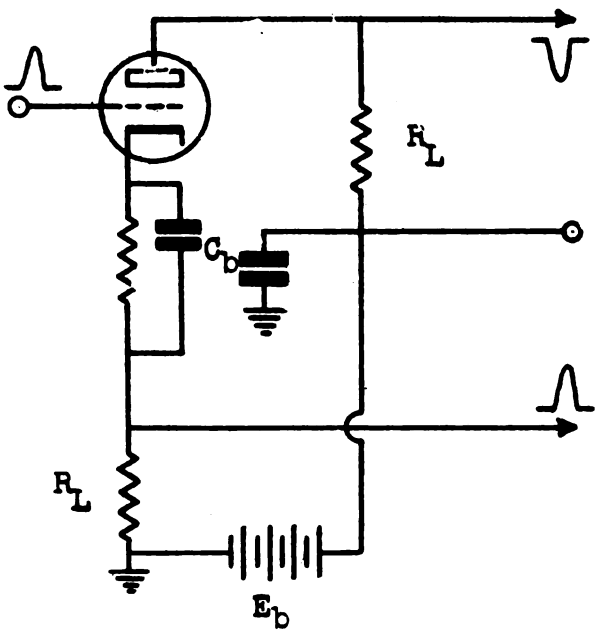

Fig.15-6: Single Tube Paraphase Amplifier.

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12. Figure 6 is typical of the former type. If the plate and cathode load resistors have the same value the two output voltages will be equal in amplitude since the same load current flows through both. The polarities of the output voltages will be opposite with respect to ground.

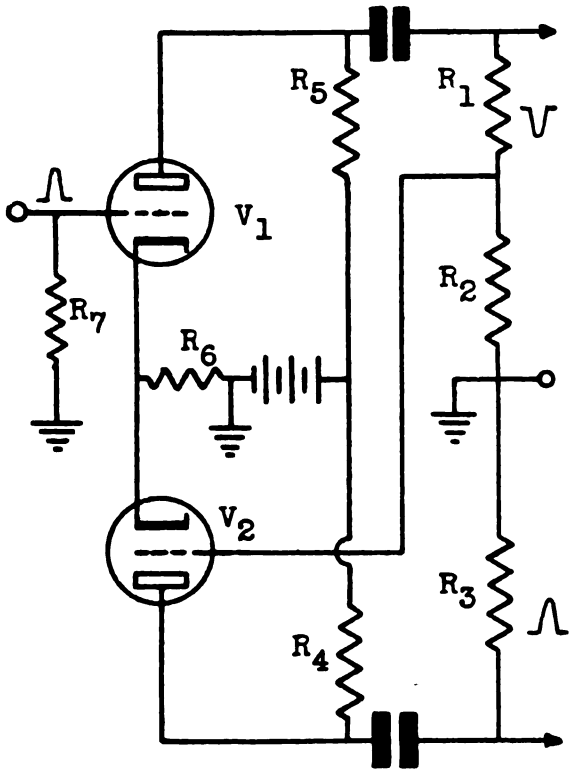

Fig. 15-7: Two Tube Paraphase Amplifier.

13. The Two-tube Paraphase Amplifier, Figure 7, consists of one tube (V_1) which acts as a conventional amplifier and another (V_2) which is fed from the output of the first by way of a voltage divider, R_1 and R_2, which should nullify the gain of the first tube. This condition is satisfied when the value of R_2 is so adjusted that the voltage variations across it are of the same amplitude as the input to V_1. This will then provide V_2 with an input signal of the same amplitude as that applied to the grid of V_1 but of the opposite polarity due to inversion in V_1. The output of V_2, because of its polarity inverting properties, will be of the opposite polarity to its input and therefore to the output of V_1. Assuming that the two tubes and their plate load resistors, R_4 and R_5, are matched, the output signals will be equal in amplitude.

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CHAPTER XVI

Electromagnetic Sweep Generation

1. Electromagnetic sweep generation is utilized to produce deflection of the electron beam in a cathode ray tube by causing the beam to travel into a magnetic field, the intensity of which can be increased at some known rate. It is found desirable to utilize electromagnetic means of focusing in conjunction with a system generating an electromagnetic sweep. Thus cathode ray tubes may be considered as of two distinct types; (a) electrostatic and (b) the electromagnetic. Each has peculiar characteristics which to a great extent determines its scope of application.

2. Following is a list of the characteristics, both good and bad, of electrostatic and electromagnetic types of cathode ray tubes:

Electrostatic CRT

(Good)

1. Readily available in small sizes.
2. Requires low power.

(Bad)

1. Requires high voltage.
2. Large, bulky, difficult to make in large sizes.
3. Greater length required.
4. Very high voltages for large angles of deflection.
5. External seals for large sizes.
6. Subject to vibration.

Electromagnetic CRT

(Good)

1. Easy to make in all sizes.
2. Small in size, short in length.
3. Low voltage required, 30-40 volts.
4. Wide angles or deflection for short length.
5. Not subject to vibration.

(Bad)

1. Requires relatively high power.

3. Magnetic Deflecting Force: A magnetic field exerts a force on a moving electron due to the fact that a moving charge is an electrical current, and a magnetic field produces a force upon a current. This force produced by the magnetic field is at right angles to both the magnetic field and the direction of movement of the electron. It is proportional to the charge of the moving particle, to the magnetic flux density, and to the component of the velocity that is at right angles to the magnetic field.

4. In order that magnetic forces may be used for deflection, the magnetic field is set up by passing current through a coil, or coils, situated so that the axis of the coils intersects the axis of the electron beam at right angles. The lines of magnetic force thus produced are at right angles to the direction of the electron motion. Under these circumstances, the electrons experience a force, due to the magnetic field, that urges them to move at right angles to both the magnetic lines of force and their direction of motion.

ELECTROMAGNETIC FOCUSING

5. The electrostatic

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forces considered in the electron gun in Chapter XIV may be replaced by corresponding magnetic forces. The magnetic forces are set up by passing current through a coil of wire the axis of which corresponds with the axis of the focusing system. This radial coil is shown surrounding the neck of a cathode ray tube in Figure 1.

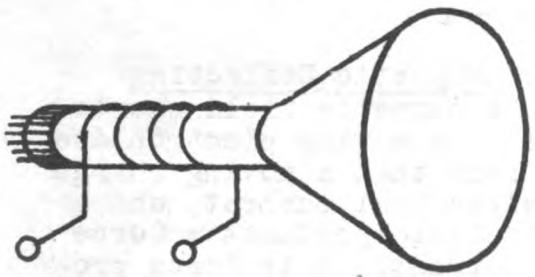

Fig. 16-1: Radial Focusing Coil.

6. The priciple underlying magnetic focusing may be examined in terms of the magnetic lines of force set up by the coil. Consider the system shown in Figure 2.

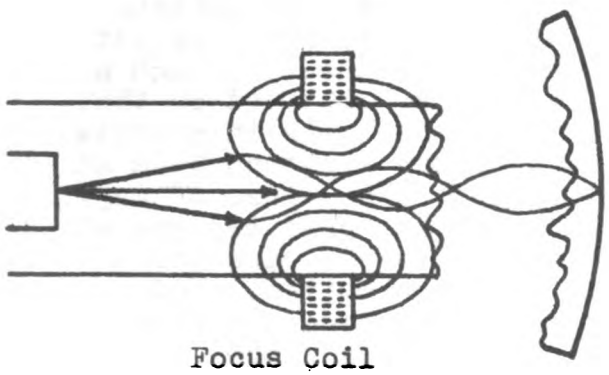

Fig. 16-2: Magnetic Focusing of and Electron Beam.

Surrounding the tube is a focusing coil. The lines of magnetic force produced by the coil extend the thickness of the coil, parallel to the direction of electron motion.

7. The electrons experience a force from the magnetic field only if their motion is at an angle to the lines of magnetic force. If the line of motion and lines ofmagnetic force are parallel, the electron is urged to move only by the attracting force from the anode. However, if the electron leaves the cathode at a slight angle to the axis of the system, then a force is exerted on it by the magnetic field. The direction of this force is at right angles to the motion and to the magnetic lines of force. The force acts, in the case shown in Figure 2, into the plane of the paper, and the electron travels in a spiral path, urged forward by the anode and to the side by the magnetic force. There will by some point along the axis of the tube which will be reached by all the electrons, regardless of their initial angles of motion with respect to the axis. At this point the screen should be located, as this represents the point of focus of the electron beam.

8. In practice, the electrons leave the cathode at different initial speeds and at various angles with respect to the axis of the tube. But the time required for any electron to complete the circle in its spiral flight depends only on the strength of the magnetic field. Hence, all electrons from the cathode complete the circle in the same time, provided only that the magnetic field is uniform.

9. The strength of the magnetic field may be controlled by the amount of current passing through the coil and by the number of turns in the coil. For a given coil, the magnetic field may be varied by varying the current until the electrons are focused on the scanning surface.

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ELECTROMAGNETIC DEFLECTION

10. In Radar indicators it is usually necessary that deflection of the beam in a cathode ray tube be increased linearly with respect to time. Since the deflection is proportional to the deflecting force, linear deflection is obtained by applying a deflecting current that increases linearly with respect to time. When the end of the sweep is reached, the deflecting force must reverse itself and decrease rapidly to its original value. The deflecting forces must, in other words, have a shape shown in Figure 3, when plotted against time.

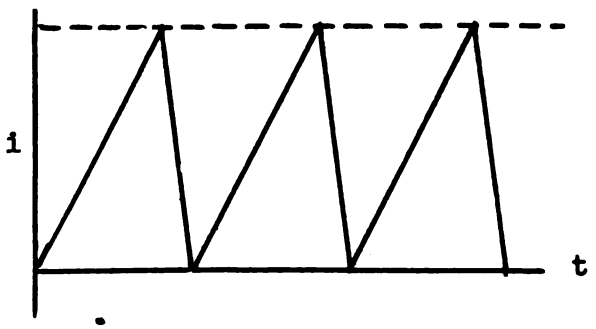

Fig. 16-3: Current through a Deflection Coil to Produce a Linear Sweep.

11. Producing a Linear Rise in Current Through an Inductance: The sweep waveform of voltage as produced in a sweep generator for electrostatic deflection cannot ordinarily be used as a source of saw-tooth waves of current required for magnetic deflection. The deflection coils in the magnetic system have the property of electrical inductance, combined with some inherent resistance. When a periodic voltage wave is applied to such a resistance-inductance combination, the corresponding periodic current does not have the same wave shape, except in the two cases of which are of interest in Radar, since they are nonlinear with respect to time.

12. It is necessary to determine, therefore, what form of voltage wave must be applied to a resistance-inductance combination to produce a linear rise of current. This may be done by considering first an ideal deflecting coil composed of inductance only. Referring to Chapter III, it will be found that the current in a pure inductance can be made to change linearly with time, only if an instantaneous change in voltage is applied across the inductance. These waveforms are shown in Figure 4.

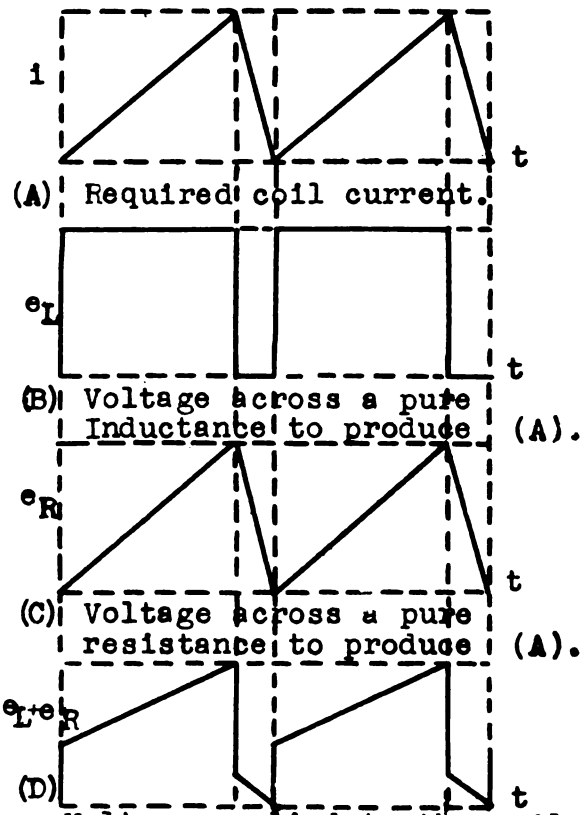

Fig. 16-4: Voltage Applied to a Coil to Produce a Linear Current Through it.

The voltage wave consists of sharp, instantaneous impulses the height of which corresponds to the desired rate of change of current in the inductance.

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The coil must, however, contain some resistance. It is obvious that a linear rise in current through a resistance is produced by a linear rise in voltage across it, Figure 4 (C). Then the voltage applied to a practical inductance should be the sum of these constant voltage values, Figure 4 (D). Thus a "trapizoidal" voltage applied to a deflection coil will produce a linear current through the coil.

13. Peaking Resistor: The combination of square wave and saw-tooth voltages in Figure 4 must be produced in the sweep generator. The manner in which this voltage wave is produced is illustrated in Figure 5.

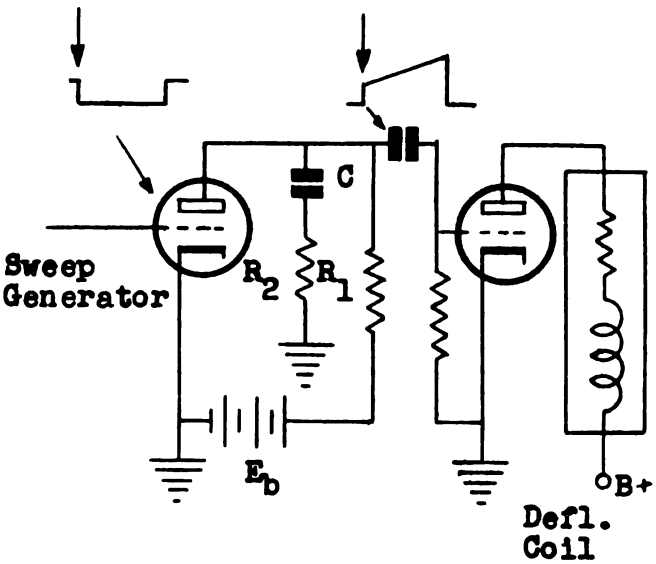

Fig. 16-5: Circuit employed to Produce a Trapizoidal Voltage.

Here C is the capacitor charged through the two resistors R_1 and R_2 from the voltage source E_b. The synchronizing pulses necessary to make the circuit operate are applied to the grid of the sweep generator. The output voltage waveform is taken across capacitor C and the peaking resistor R_2. The part of the voltage appearing across the capacitor is a saw-tooth wave as shown in Figure 6(A), in no way different from that produced in the simple electrostatic deflecting circuit. The voltage appearing across R_2 must be considered in two categories. When the condenser is charging, the voltage across the resistors R_1 and R_2 is the reverse of that appearing across the condenser (since the sum of the voltages must equal the constant voltage E_b).

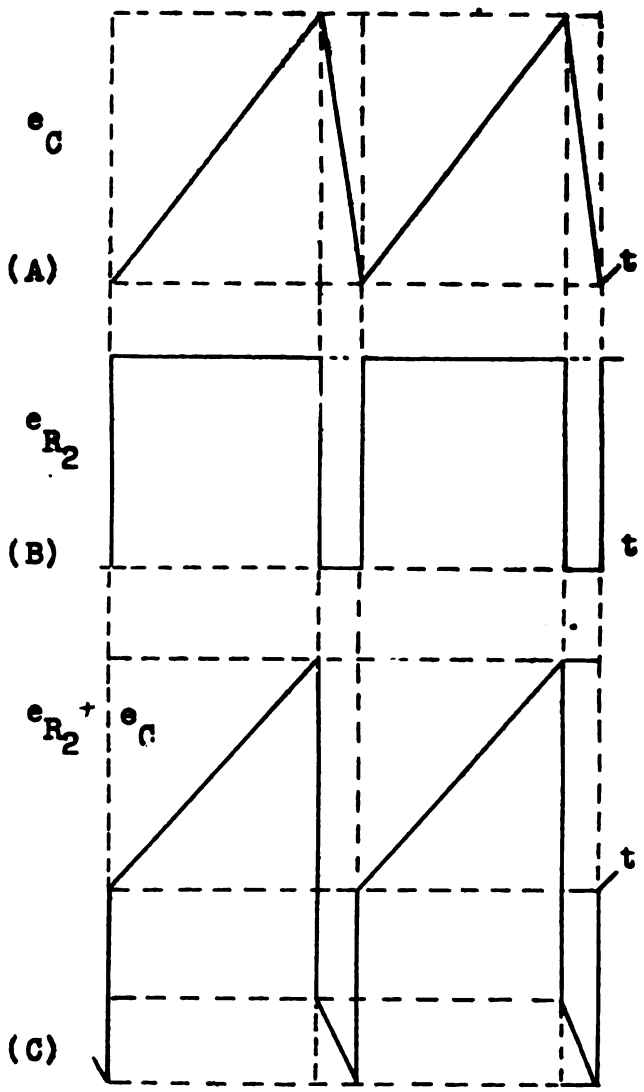

Fig. 16-6: Waveforms in a sweep Generator Circuit Employing a Peaking Resistor (R_2).

When the condenser starts to discharge (as the sweep generator tube fires) the voltage

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across C and R_2 is suddenly shunted by the low resistance of the tube. The voltage across the capacitor cannot change suddenly; hence the difference in voltage must appear suddenly across the peaking resistor R_2. After the initial change of voltage, the condenser discharges until the tube suddenly becomes nonconducting; that is, at the end of the synchronizing pulse applied to its grid. Then the voltage in the circuit suddenly rises to the battery voltage E_b. The capacitor voltage cannot change instantaneously, so the voltage across R_2 changes suddenly, as shown in Figure 6(B), and thereafter the capacitor charges at the rate determined by R_1 and R_2 in series. Since the charging or sweep time will be limited to the most linear part of the charge curve by the proper selection of R_1 and R_2 a constant current may be considered as flowing to charge the condenser at such a linear rate. (See Chapter III, paragraph 35). A constant current flowing through R_2 will produce a constant I R drop across it. This square voltage pulse in series with the linear voltage rise across the condenser results in the combination waveform, part impulse, part sawtooth, shown in Figure 6(C). Such a voltage, applied to deflecting coils, will produce a linear rise of current. By adjusting the relative values of C and R_2, the amount of peaking impulse, relative to the sawtooth amplitude, may be set at any desired value to match any given combination of resistance and inductance in the deflecting coils.

14. Damping Resistance Across Deflecting Coil: In many cases the rapid change in current through a deflecting coil at the time of retrace causes the coil to be shocked into oscillation. If the Q of the coil is sufficiently high, the damped oscillations will continue during the next sweep, as shown in Figure 7. This will cause a very nonlinear sweep at the beginning of each trace. Such oscillations may be damped in amplitude by placing a resistance of approximately 20,000 ohms in parallel with the deflecting coil, so that they have died out before the next trace starts.

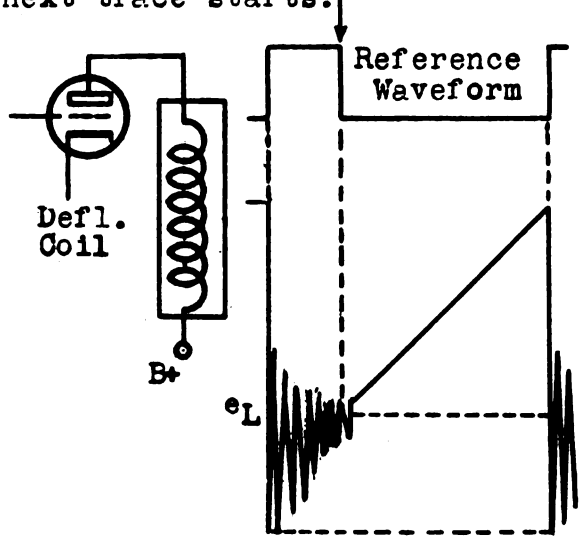

Fig. 16-7: Oscillations in Coil Current During and After Retrace.

The Waveform of the voltage across the coil will then be as shown in Figure 8.

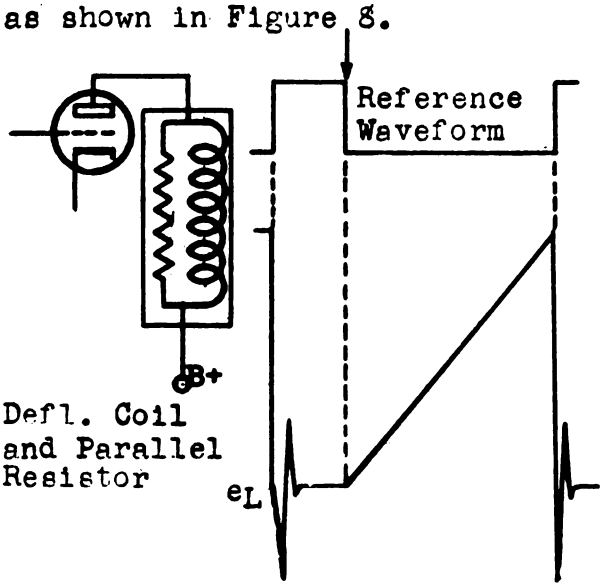

Fig.16-8: Damped Oscillations in Coil Current.

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A diode may be used as the damping resistance, in which case the cathode of the diode is connected to the plate of the deflection amplifier output tube and the plate connected to the plate supply end of the coil. This arrangement is shown in Figure 9.

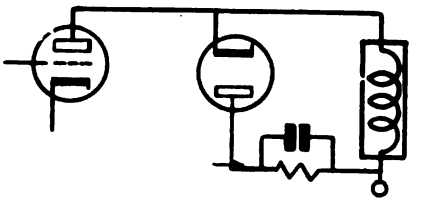

Figure 16-9: Diode Used As Damping Resistance.

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CHAPTER XVII

Sweep Control Systems

1. In certain types of Radar equipment, such as airborne models ASC, ASD, and ASG, and in numerous models of shipborne gear such as SC, SG, FC, and FD, the antenna, which serves the dual purpose of transmission and reception of radio frequency energy, must be rotated or moved about some axis, usually the horizontal, in order to obtain information concerning the surrounding area on the indicator screen. Therefore, some system for controlling the rotation of the antenna and synchronizing its movement with an indicating device on the Radar indicator proper is necessary if the operator is to be fully informed at all times of the data being received. The indicating device may be a simple moving indicator to show the bearing of the antenna with respect to the ship's head or with respect to due north. It may be the trace or sweep on a cathode ray tube screen which sweeps out from the center radially and rotates in synchronization with the antenna, presenting a type P picture, or it may be the sweep on a cathode ray tube screen which moves backward and forward across the screen instep with the oscillating or scanning motion of the antenna, presenting a type B picture. No matter what indication is given, whether it be mechanical or visual, as on a cathode ray tube, the necessity for a control system exists in order to coordinate the information being received. The smoothest and most efficient means of obtaining this control is utilizing either the selsyn (self-synchronizing) control system or the potentiometer control system.

THE SELSYN SYSTEM

2. Motor, Generator and Transformer Action: Reviewing briefly motor, generator and transformer action, it will be remembered that if a magnetic field is applied in the locality of a bar magnet or an electromagnet, the magnet will attempt to align itself with that field. This holds also when the applied magnetic field is alternating and the magnet has an alternating current flowing through its winding so that its field is alternating. It should be remembered also that if a conductor moves through a magnetic field a voltage is produced between its ends. Similarly, if a moving or changing magnetic field cuts a stationary conductor a voltage is developed between its ends.

3. The Synchro Generator: Keeping these basic facts in mind, examine first the part of a simple selsyn system called the synchro generator (synchro for synchronous). If an alternating voltage is applied to the rotor of the synchro generator the voltages induced in the stator windings will be in phase but will differ in amplitudes. In other words, for any rotor

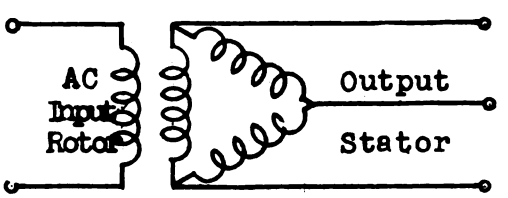

Fig. 17-1: The Synchro Generator

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position there will be voltages induced in the stator windings which will depend upon the actual physical position of the rotor with respect to the coils. Therefore, if the rotor were turned, different voltages would appear across the coils as the rotor assumed different positions. The output voltages from the synchro generator can be taken from the three taps on the stator windings.

4. The Synchro Motor: The synchro motor is identical to the synchro generator in design in that it consists of a rotor and a three winding stator. Assume that AC voltages of different amplitudes are applied to the synchro motor stator windings and that an AC voltage is applied to the rotor winding. There will be a flow of current in the stator windings since the voltages across them are unequal,

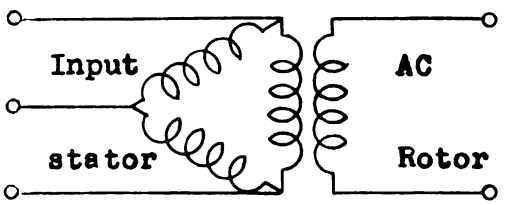

Fig. 17-2: The Synchro Motor.

and the current will cause a magnetic field to cut the rotor, which is, in effect, an AC electromagnet. The rotor will then attempt to align itself with the field produced by the stator so that the voltages induced into the stator windings by the rotor will cause the voltages across the coils to be equal in amplitude.

5. Simple Selsyn System: By connecting the output of the synchro generator to the input of the synchro motor and applying an AC voltage to both the rotors a simple selsyn control system is formed. Now with any position of the rotor of the synchro generator there will be voltages induced in the stator and these voltages will be impressed across the coils of the motor stator. If there is any difference in the amplitudes of the voltages,

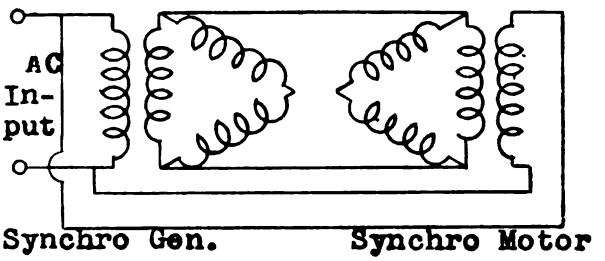

Fig. 17-3: The Simple Selsyn System.

current flows in the coils producing a field in which the rotor, since it also has current flowing in it continuously, attempts to align itself and by so doing induces voltages into the stator coils so that the differences in amplitudes become zero and current no longer flows. Thus as the rotor of the synchro generator is rotated the rotor of the synchro motor will follow, always attempting to keep the current flow in the stator windings at zero.

THE AMPLIDYNE

6. The amplidyne generator is a dynamo-electric power amplifier. In a simple system a mechanical power amplifier might consist of two or more generators in series. In Figure 4 the output of one generator whose field voltage and current is controlled by a variable resistance is connected to the field of the second generator which is mechanically coupled to the same shaft turning the first. If the field current is varied in the first generator the final voltage will be considerably larger than the controlled input voltage. Thus a DC voltage has been "amplified" or in-

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creased through the use of a mechanical amplifier so that the control resistance may actually change the output voltage of the system by a large amount by making only a small change at the input.

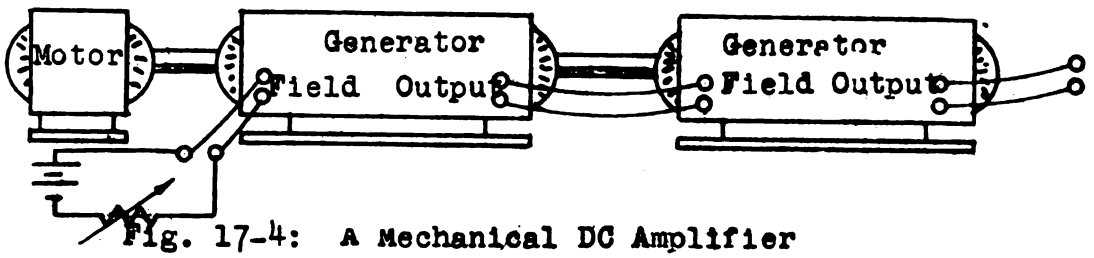

Fig. 17-4: A Mechanical DC Amplifier

7. In practice, the amplidyne consists of a single unit, the amplidyne generator and the motor driving it being on the same shaft and housed in the same shell. The principle of the amplidyne is comparable to that of a conventional DC shunt generator.

8. If a field is applied to the generator shown in Figure 5, a voltage will be developed across the brushes shown. This voltage will be proportional to

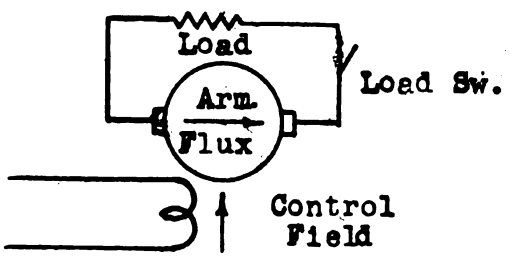

Fig. 17-5: DC Shunt Generator.

the field flux which produced it. If the load switch is closed a current will flow through the load and the armature windings, causing an armature flux to be produced as shown at right angles to the original control field. This flux or magnetic field is proportional to the armature current.

9. If the load is removed from the generator and the brushes short circuited as shown in Figure 6, a high armature current flows causing a very large armature flux to be produced since the armature resistance is of a relatively low value. Since the control field flux produced a voltage

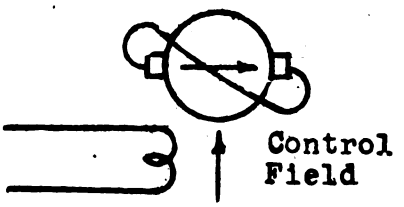

Fig. 17-6: Shorted Turn in Armature of DC Shunt Generator.

in the armature at right angles to its lines of force, it follows that a voltage will be induced back into the armature by the large armature current at right angles to its flux. This voltage will be proportional to the armature flux caused by the current flowing between the shorted brushes.

10. Placing a second set of brushes on the armature and connecting a load circuit to them as shown in Figure 7 causes a current to flow in the armature between these two brushes and a field is produced in this axis. This third field is in direct opposition to the control field and under the conditions shown the control field would be overpowered.

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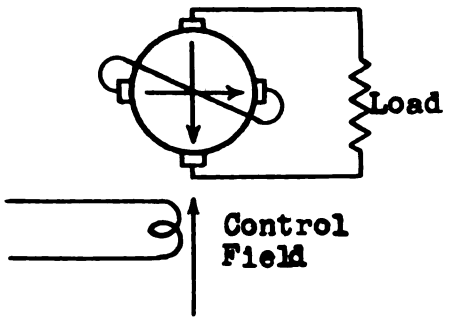

Fig.17-7: The Addition of a Second Pair of Brushes to the DC Generator.

11. If the current drawn by the load is passed through a series winding as shown in Figure 8, a field is produced which exactly neutralizes the armature flux opposing the control flux and the control field need only be strong

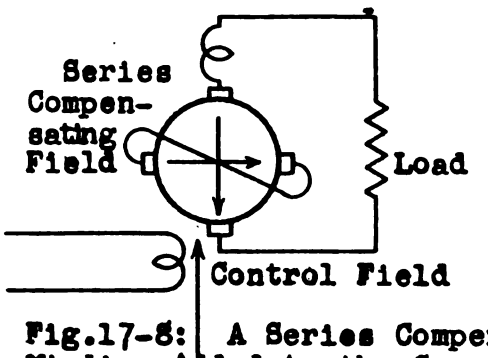

Fig.17-8: A Series Compensating Winding Added to the Generator.

enough to force its flux through the low impedance path of the armature.

12. The high amplification factor of the amplidyne, usually about 5000 to 1, makes it necessary to remove all the residual magnetism from the control field flux axis. Otherwise, a voltage will appear at the output of the amplidyne, even though no current is flowing in the control field. To accomplish the demagnetization, an alnico bar magnet is mounted on the end of the amplidyne armature and the permanent field it produces generates an alternating voltage. This alternating voltage is applied to two opposed windings in the flux axis of the control field. (See Figure 9). The resulting AC field completely neutralizes residual magnetism in the armature and field structure in periods during which the flux from the control field is zero (Zero current).

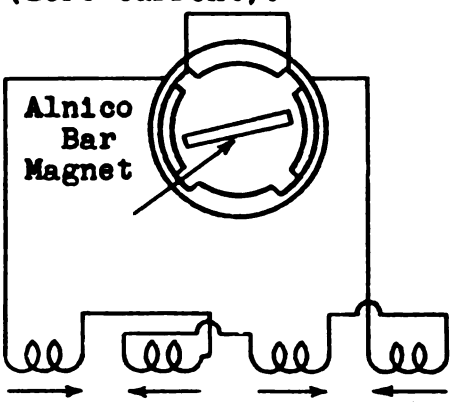

Fig.17-9: Additional Windings to Eliminate Residual Magnetism.

ANTENNA AND SWEEP SYNCHRONIZATION

13. The Rotating Coil: One method of synchronizing the rotation of the antenna with the rotation of the sweep on the screen of a cathode ray tube as when presenting a type P scan, is the use of a deflection coil or yoke around the tube which can be rotated mechanically in step with the antenna. This method entails the application of a selsyn system which does not drive any mechanical device directly but feeds its output into a control amplifier which in turn applies the controlling voltage to the control field of the amplidyne, the output of which drives the mechanical device, in this case the spin motor or rotation motor of the antenna. The block diagram for such a system is shown in Figure 10. In this instance the output of the synchro generator is fed into another selsyn device, the synchro transformer. It is the same as the synchro motor except that the output is taken from the synchro transformer rotor as

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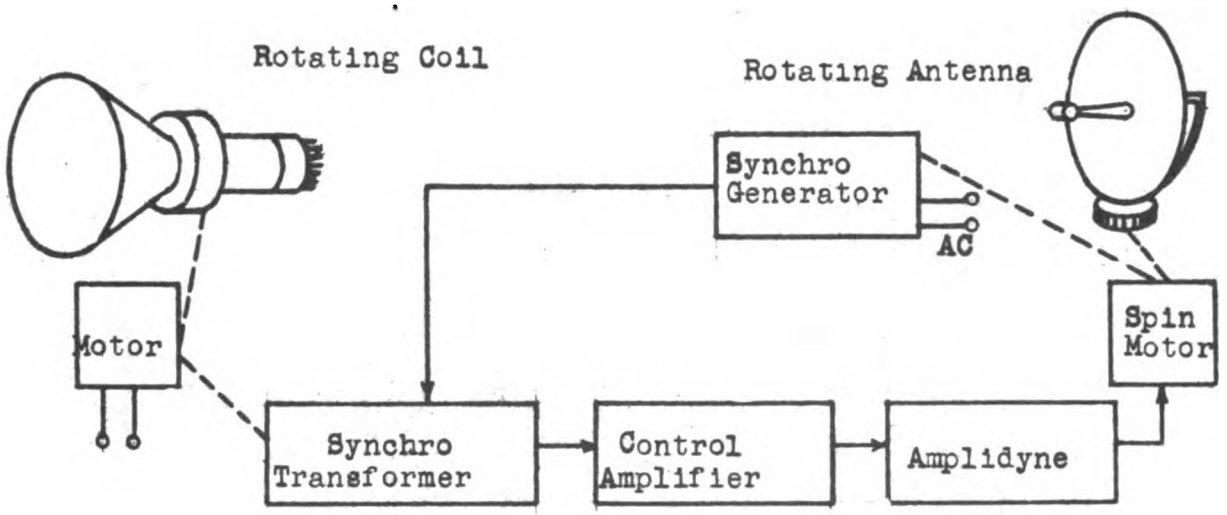

Fig. 17-10: Block Diagram of a Sweep Synchronization System Employing a Rotating Coil.

electrical energy instead or from the shaft of the synchro motor as mechanical energy or torque. Another difference is that the rotor of the synchro-transformer is the device whose movement is mechanically coupled to the deflection coil and the spin motor can actually be said to be synchronized with the sweep or trace caused by the deflection coil.

14. The control amplifier is an electronic circuit between the synchro transformer and the amplidyne that functions to amplify the AC signal from the synchro transformer and convert it into DC voltages for the control fields of the amplidyne generator. It consists of a two stage vacuum tube amplifier, the first stage for voltage amplification, the second stage for power gain.

15. In order to trace the operation of the control amplifier, Figure 11, assume that the rotor of the synchro transformer is in such a position that a voltage is induced in it. The voltage induced in the rotor is applied to the primary of transformer T_1. Assume at the instant under consideration that the polarity of transformer T_2 is such that the plates of V_1 and V_2 are positive. It will be noted from the diagram that whenever the plates of V_1 and V_2 are positive those of V_3 and V_4 will be negative with respect to their cathodes and vice versa. Now consider further that the phase of the voltage from the synchro transformer is such that at the same instant point "A" will be positive and point "B" negative.

16. Under these conditions the grid of V_1 will be more positive than the grid of V_2 and more current will flow through R_1 than through R_2. This will cause condenser C_1 to become more highly charged than C_2. In the following alternation of the line AC, the plates of V_3 and V_4 will be positive and, by reason of the higher charge on condenser C_1, the grid of V_3 will become more negative than that of V_4. Thus the plate current flow in V_4 will be greater than that in V_3 and the amplidyne control fields will be correspondingly unbalanced. It should be noted that in this half of the cycle V_1 and V_2 will not conduct since their plates are negative.

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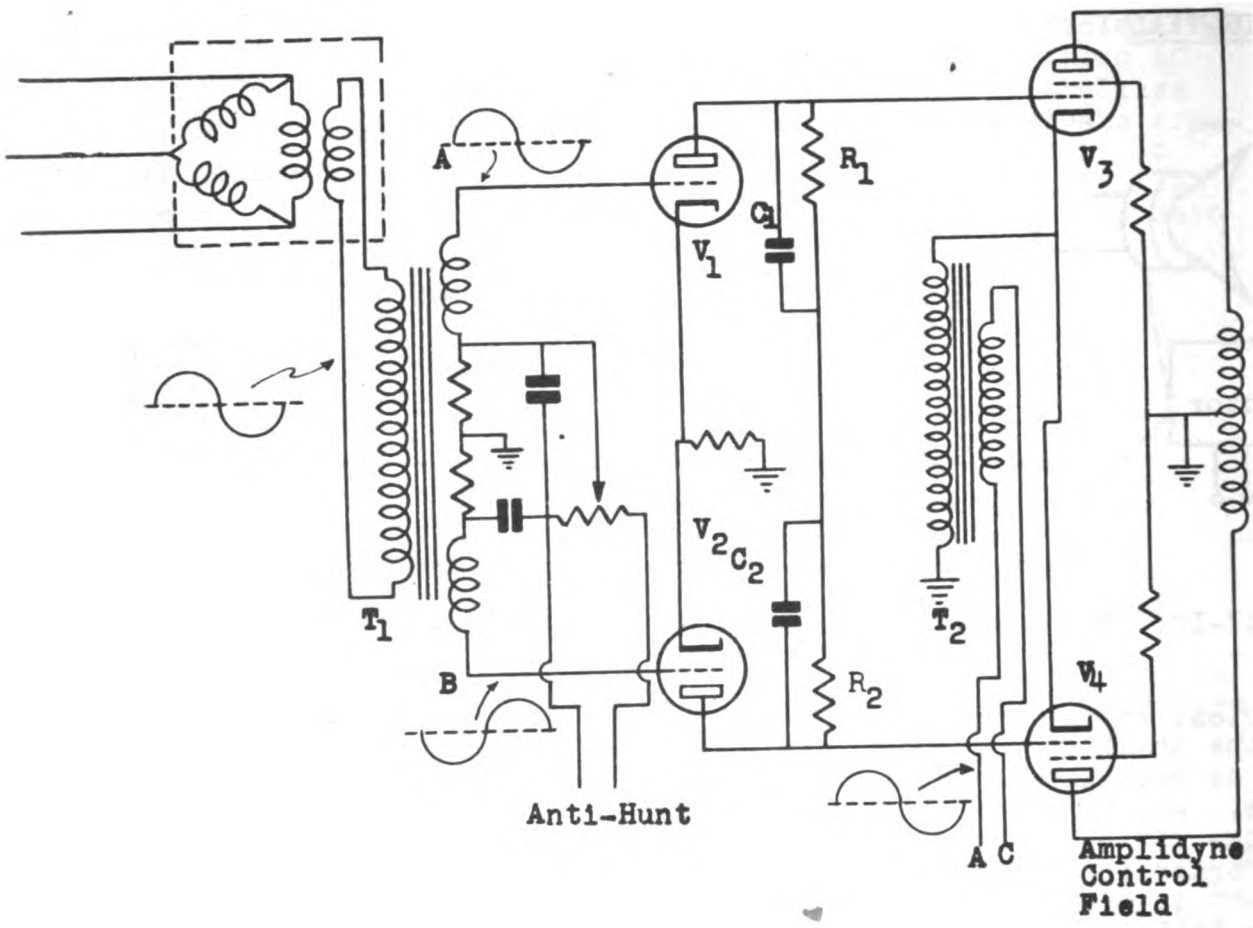

Fig.17-11: Control Amplifier.

17. The unbalance of the current in its control field will cause the amplidyne to generate a voltage and the antenna spin motor will operate to turn the antenna in the appropriate direction. Bearing in mind that the rotor of the synchro generator is tied mechanically to the antenna, it is seen that the rotation will restore the rotor to such a position that the voltages induced in the stator windings and transferred to the stator windings of the synchro transformer will not induce a voltage into its rotor. Therefore, with no voltage output from the synchro transformer, into the control amplifier, there will be no output from that unit into the amplidyne and consequently the output of the amplidyne will be zero voltage and the spin motor will remain in a stationary condition. However, if the rotor of the synchro transformer is moved, either with a hand crank or by a small motor, a voltage will be induced in it and the system will start functioning again with the spin motor attempting to allow the synchro generator to "catch up" with the rotor of the transformer. It is an easy matter, therefore, to gear the deflection yoke of the cathode ray tube to the rotor of the synchro transformer so that each movement of that unit's rotor will cause a corresponding movement of the spin motor on the antenna.

18. Hunting: In practice the training or aiming of the antenna by the control amplifier

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is complicated by the problem of oscillation of the antenna about its final position. This oscillation, called "Hunting", is caused by the tendency of the antenna to overtravel. The overtravel turns the rotor of the synchro generator past the point of zero voltage, inducing finally in transformer T_1 a voltage of opposite sign to that which caused the previous rotation of the antenna. This voltage unbalances the amplifier in an opposite direction to the previous unbalance, so that the antenna is swung back, again overtravels, is reversed once more, and so on.

19. To prevent this oscillation from occurring an anti-hunt circuit is employed. This involves feeding back voltages from the output of the amplidyne to the grids of tubes V_1 and V_2. These voltages are of a magnitude and a polarity such as to oppose the antenna movement as it approaches the correct position. They are fed through a resistance-capacity network to the amplifier input. A potentiometer is used to adjust the feedback for the proper amount to stop hunting.

20. The Selsyn Motor: Another simple means of obtaining synchronization between antenna and sweep rotation is a selsyn device consisting of a rotor and two windings on the stator. (See Figure 12). In performance, the selsyn motor is a transformer whose primary may be actually reversed physically with respect to the secondaries. With this arrangement a signal may be put into the primary and taken from the secondaries in opposite polarities, that is, push-pull, and the amplitudes of the signals will vary as the rotor is turned. The application of this system, as far as sweep synchronization is concerned, is made by mechanically coupling the rotor of the unit to the antenna so that each rotation of the antenna unit will cause a complete revolution of the rotor.

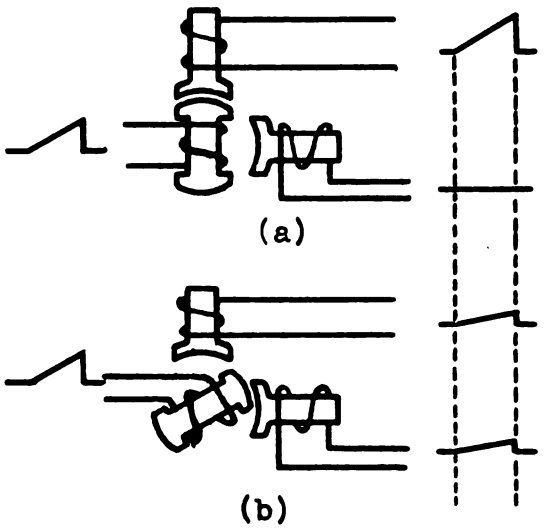

Fig. 17-12: Selsyn Motor.

If a sweep wave form is applied to the primary or rotor of the selsyn motor, then sweep waveforms will appear at the two secondaries. The two waveforms will be out of phase by 90° and as one increases the other will decrease and vice versa. These voltages can then be amplified and applied to deflection coils mounted at right angles to each other around a cathode ray tube to produce a sweep which moves outward from the center of the screen and also rotates around the tube as the selsyn motor turns in synchronism with the antenna.

21. The Potentiometer Control: In presenting a type B picture on a cathode ray tube the trace must sweep from bottom of the screen toward the top and also backwards and forwards, that is, from side to side. in synchronization with the oscillating or scanning motion of the antenna. This means that a sawtooth waveform at the frequency of the antenna scanning must be applied to the horizontal.

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deflecting elements of the tube. This may be obtained from a potentiometer whose arms or contacts are coupled mechanically to, and moved with, the antenna. In Figure 13, the circuit for such a system is shown. With a constant DC voltage applied to one tap of the potentiometer and the other tap grounded, each contact will go through the full voltage variation, that is, from the applied voltage to ground or zero volts, if it is swung through 180° of movement. If the scanning of the antenna unit is maintained at a linear speed, then the voltage rise from zero to full voltage, or the decrease from full voltage to zero, will be at a linear rate and the trace will be deflected from side to side at the linear rate desired.

In practice, the output of such a system is taken from the two contacts and applied to the horizontal deflection coil without any amplification.

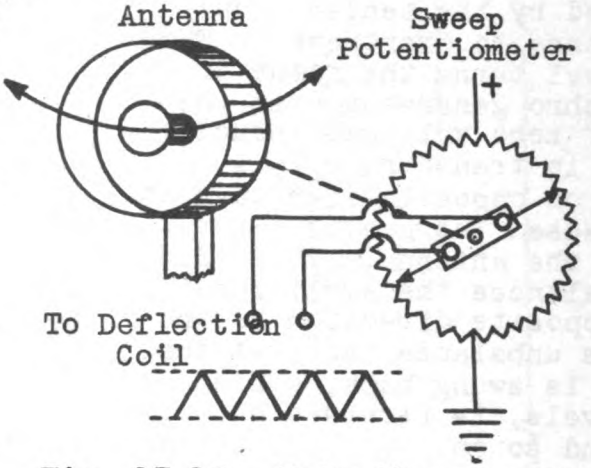

Fig. 17-13: Potentiometer Sweep Control.

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CHAPTER XVIII

Range Marker Circuits

1. A range marker circuit is any circuit, either an external unit or an integral part of an indicator, that supplies sharp voltage pulses of accurately controlled frequency, synchronized with and superimposed on the sweep to produce an indication of range.

2. One of the most valuable applications of Radar is that of determining the range or distance from a Radar location to the target under consideration. Determination of azimuth angle and elevation angle are also important but without a knowledge of range this other information cannot be put to maximum use. Therefore, considerable importance is attached to the devices used to indicate distance from a target. The simplest means of obtaining this calibration would be the use of a transparent scale on the face of the indicator cathode ray tube, and in certain types of Radar equipment, this system is used. At first hand this might seem to be the ideal solution to the problem but it must be remembered that in order for the scale to be accurate the linearity of the sweep and length would have to remain constant at all times. Therefore, some system of placing markers on the trace, which will always be the same distance apart as far as time and range are concerned, is necessary so that variations in linearity or in length of the trace will not change the calibration.

3. Shock Excited Oscillators: The simplest form of range marker circuit consists of an LC circuit which is shocked into oscillation at the beginning of the sweep. If the Q, or inductive reactance to resistance ratio, of the coil in the resonant circuit is high enough, damped oscillations will continue for the time-duration of the sweep. See figure 1.

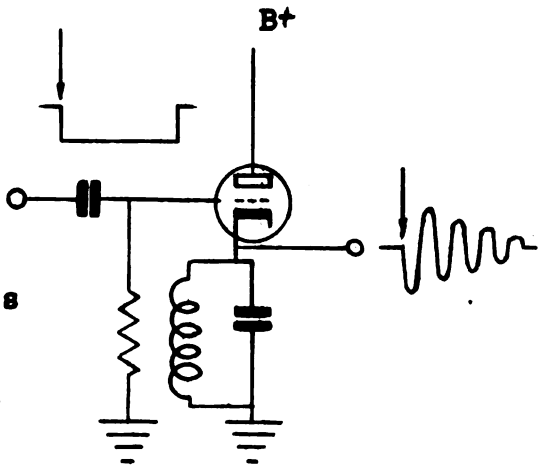

Fig. 18-1: Simple Range Marker System.

This damped sine wave can be applied to the deflecting elements of a cathode ray tube to give a rough estimation of range. By choosing the resonant frequency of the LC circuit so that the period is 12.34 microseconds (the time required for a radio wave to travel out one nautical mile and return), or a multiple of 12.34 microseconds, the range marks can be made to occur at 1 mile intervals, or some multiple of 1 mile, for the duration of the sweep.

4. A more refined system for procuring sharp, clean pulses to serve as range markers is shown in Figure 2. When a negative pulse is applied to the damped wave, or shock oscillator the tube is cut off suddenly, causing oscillations to occur in the LC tank of the cathode cir-

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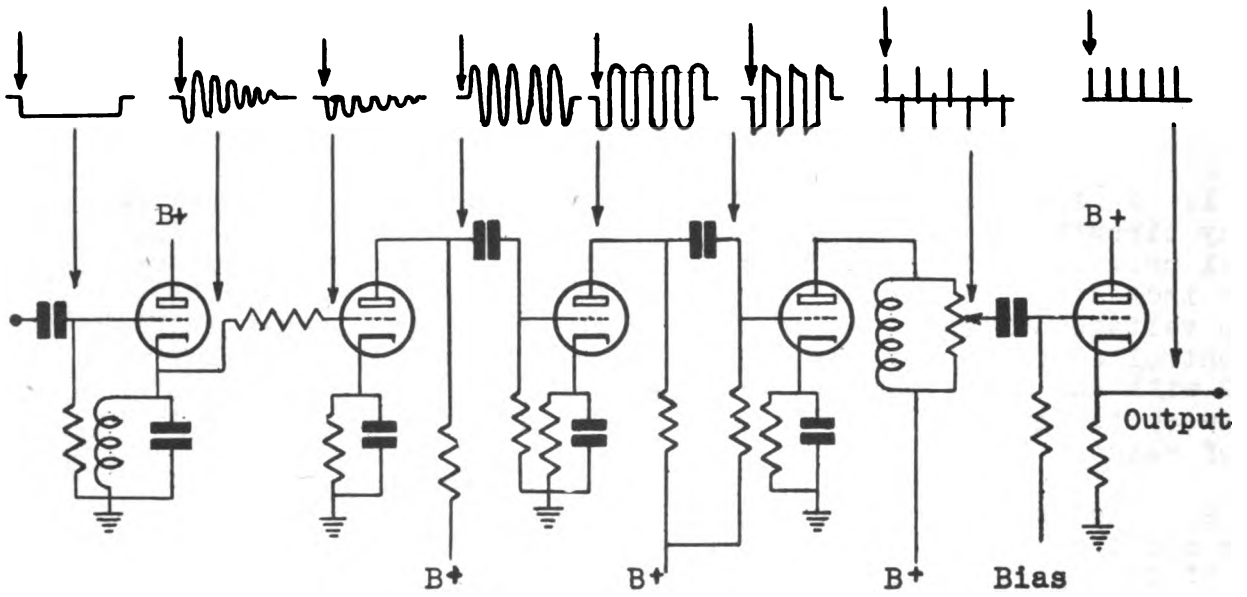

Fig. 18-2 Shock Excited Oscillator Range Marker System.

cuit. If this negative pulse lasts for the duration of the sweep, then the oscillations, even though they are damping out, will last long enough to give range markers over the entire trace. This sine wave oscillation is then applied to the grid and plate limiting stages, to an amplifying and sharpening stage, and finally to a biased cathode follower from which positive signals only appear in the output. The sharpening stage consists of an amplifier tube with an inductance and resistance in its plate circuit. The resonant frequency of the inductance, with its distributed capacity, is approximately two megacycles. The tube is driven beyond cutoff on the negative portion of the signal on the grid. This sudden change in plate current causes the coil to be shocked into oscillation. This oscillation is highly damped by the resistance across the inductance, however, so that less than one cycle occurs. Since the resonant frequency is two megacycles the period for one cycle is 0.5 microsecond, and the time for one alternation will be only 0.25 microsecond. This sharp pulse will therefore appear as a very sharp pip on the trace of the indicator tube, since its time duration is so short. When the positive portion of the grid signal is applied, the tube is driven above cutoff and the tube conducts suddenly causing another shocked oscillation of the coil. Since the tube is now drawing current and the tube's plate resistance is in series with the coil, the Q of the circuit is lowered considerably and the pulse is not as large in amplitude. This is of no consequence, however, since only the positive signal occurring when the tube was driven beyond cutoff, is used. This signal is applied to the biased cathode follower which removes all of the negative portions of the waveform and allows only the positive portions to appear in its output.

5. In addition to superimposing range markers on the sweep of the cathode ray tube so that they appear as amplitude variations of the trace, they may be used in intensity modulating a cathode ray tube so the markers appear as bright spots on the screen. This application is used in several types of data presentation, mainly types B and P scans. Thus, as the trace is swept from side to side in a type B picture, the range markers will appear as

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bright lines all the way across the screen at the intervals determined by the LC constants of the system. In a type P presentation, the markers will appear as concentric circles as the trace rotates.

6. Application of the Sustaining Multivibrator or Franklin Oscillator: Several other methods of obtaining range markers may be used so that the oscillations are not damped but are sustained at full amplitude for the duration of the sweep. One of these is a circuit known as the Franklin oscillator. In reality it is an oscillatory circuit in the grid of a tube which is shocked into oscillation at the beginning of the sweep and is sustained in oscillation by feedback from the output of the second tube. See Figure 3. The second tube is necessary in order that the proper polarity reversals will occur, allowing the signal to be fed back to the LC tank circuit so as to aid oscillations. It may be thought of as a multivibrator since it maintains recurrence of cycles by coupling the output of one amplifier to the input of the amplifier ahead of it. In this instance the frequency or recurrence of the oscillations is not determined by the RC time constants in the grid circuit of the first tube. The output of the oscillator is taken across the LC circuit and fed into a limiting and sharpening circuit as in the damped wave type of marker circuit discussed in paragraph 4.

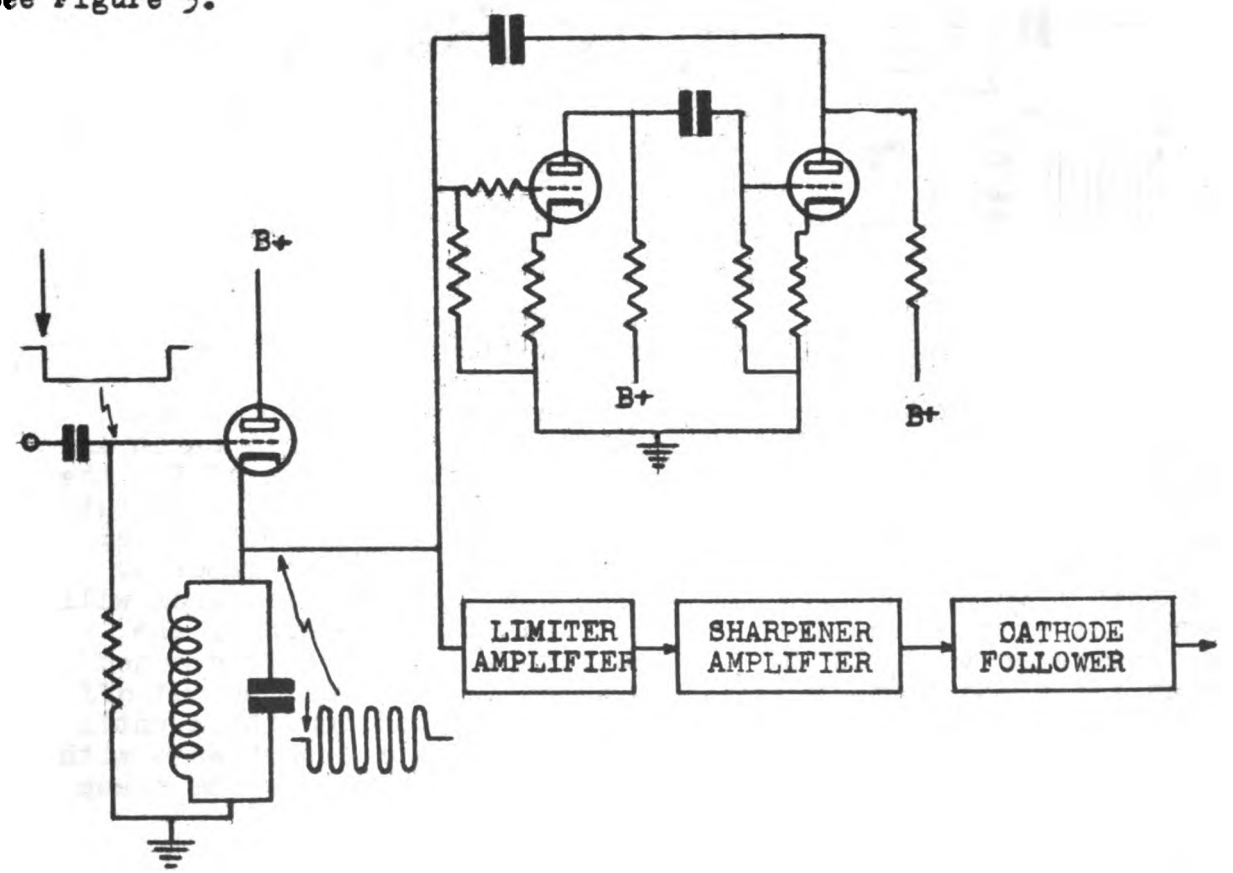

Fig.18-3: Franklin Oscillator.

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7. Range Marker Multivibrator: This range marker circuit is similar to the Franklin oscillator in that it utilizes a second tube to obtain regenerative feedback. The feedback obtained occurs between cathodes, so that sustained oscillations continue in the cathode circuit of the first tube. The feedback path from cathode to cathode is a series resonant circuit, offering zero impedance at its resonant frequency and high impedance at nearby frequencies. Oscillations therefore take place at the frequency at which there is least impedance in the feedback path.

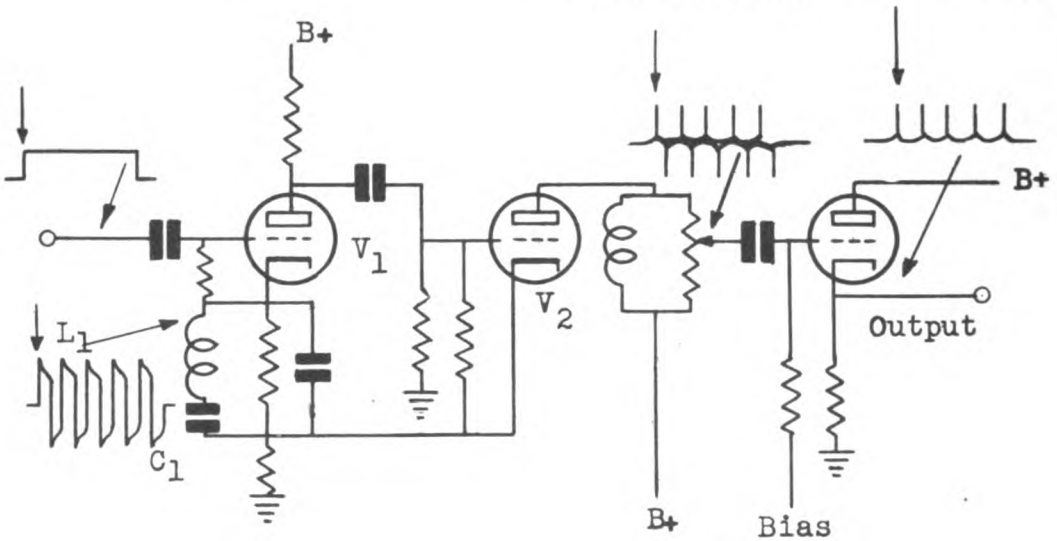

Fig. 18-4: Range Marker Multivibrator

8. In the circuit shown in Figure 4, when a positive pulse equal in time duration to the length of the sweep is applied to the grid of V_1, the voltage at the plate drops rapidly as the tube goes into conduction. This abrupt steep decrease in voltage appears at the grid of V_2 so that the plate current is decreased, causing the cathode to drop. Since the cathode of V_2 is coupled through a low impedance circuit (L_1C_1) this drop will appear at the cathode of V_1 also. This is the correct polarity to aid in causing a further increase in plate current in V_1 since a drop in cathode voltage will cause the same effect as a rise in voltage on the grid. The cathode voltage (with respect to ground) will fall to a minimum and rise in a manner that is nearly sinusoidal. As the cathode of V_1 rises the tube draws less current until finally by the feedback action from the other tube, it is cut off. The plate voltage of V_1 rises sharply as the tube is cut off causing the grid of V_2 to follow and the cathode of that tube to rise sharply because of the increase in plate current. This sharp rise causes the cathode voltage to rise and fall, producing a positive half cycle at the frequency of the series resonant circuit. Then as the cathode of V_2 falls, since it is coupled to the cathode of V_1, the tube, V_1, will be driven above cutoff causing its plate potential to drop and the cycle repeats. These sustained oscillations will continue until the end of the positive square wave is reached at which time V_1 will be cut off and held in that condition until another positive square wave with time duration equal to the sweep time is applied.

9. The waveforms produced by the range marker multivibrator differ from sine waves due to the fact that the tubes are driven beyond cut off. Since the sides

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of the waves are fairly steep, causing V_2 to conduct and cut off rapidly, the sharpening arrangement in its plate circuit functions well. This sharpening circuit consists of an inductance which is shocked into oscillations which are damped by a parallel resistor. This gives a sharp narrow pulse for every rapid change in plate current as described before in paragraph 4 of this chapter.

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CHAPTER XIX

Balanced Detectors

1. The Balanced Detector is a circuit useful for detecting changes in frequency rather than changes in amplitude, or in modified form to detect the beat produced by two varying frequencies. The former application is often used in automatic frequency control systems (AFC), the latter in the frequency modulation Radar system. Since the Balanced Detector is intimately associated with frequency modulation or frequency variations, a brief discussion of modulation is in order.

2. Modulation: Modulation is the process of altering a radio or carrier wave in accordance with the intelligence to be transmitted. The nature of the intelligence is of little importance as far as the process of modulation is concerned; it is the METHOD by which this intelligence is made to give a distinguishing characteristic to the radio wave (which the receiver will convert back into intelligence) that determines the type of modulation being used. Inasmuch as a high frequency signal is characterized by its amplitude, frequency, or phase, it can be distorted or modulated by amplitude changes, by frequency changes, or by phase changes. It is possible, therefore, to produce amplitude modulation (AM), frequency modulation (FM), or phase modulation (PM). It is possible also for any two of the types of modulation to exist simultaneously or for all three types to occur. Normally, however, only one type of modulation is desirable in any given system. If the other two exist simultaneously they areusually undesirable byproducts. For this reason in modulation and detection the elimination of the undesirable byproducts may be of as much importance as the system selected.

3. Since phase modulation is similar in many respects to frequency modulation, the remaining references will involve FM and AM only.

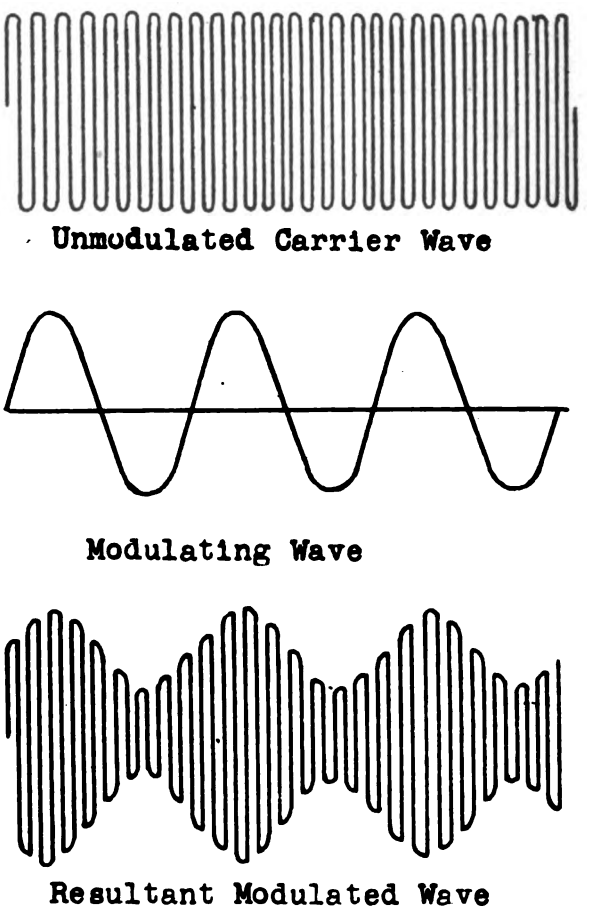

Fig. 19-1: Amplitude Modulation

4. Comparison of AM and FM
Figure 1 represents an oscillogram of an RF carrier wave amplitude modulated by a sine wave of AF voltage. After modulation the resultant RF wave is observed

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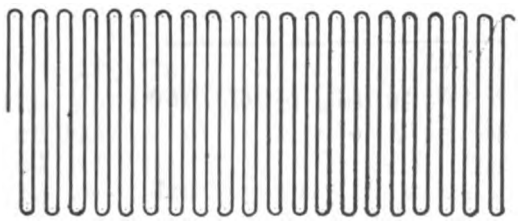
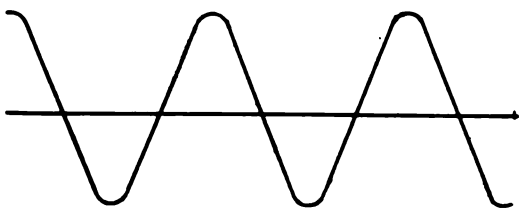
to vary about the zero axis at a constant rate as before, but the STRENGTH of the individual RF cycles is now proportional to the amplitude of the modulating voltage.

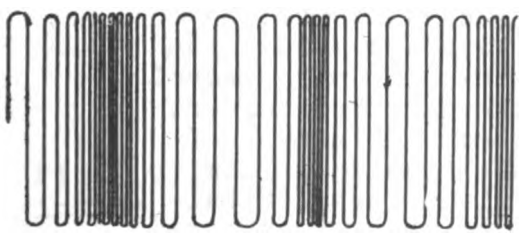
5. In Figure 2 is shown the same carrier wave frequency modulated by the same modulating voltage. Here it may be seen that a modulation voltage of one polarity causes the carrier frequency to decrease, as shown by the fact that the individual RF cycles of the carrier are spaced farther apart.



Unmodulated Carrier Wave



Modulating Wave



Resultant Modulated Wave

Fig. 19-2: Frequency Modulation.

A modulating voltage of the oppo.ite polarity causes an increase in the frequency of the carrier as shown by the RF cycles being squeezed together allowing more of them to be completed in a given time interval.

6. A careful examination of Figure 2 will reveal that the amount of variation from the normal carrier frequency is proportional to the AMPLITUDE of the modulating wave. In frequency modulation practice this is termed "deviation" and should be independent of the frequency of the modulating wave. The frequency of the modulating wave does however determine the RATE at which the carrier RF is varied. Thus in FM the desired intelligence (an audio frequency in this case) is superimposed upon the RF carrier, the amplitude of the AF being expressed in terms of the extent of RF carrier frequency variation and the AF frequency by the rate at which the RF is varied.

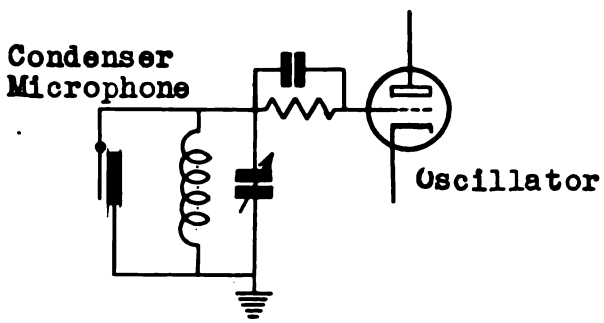


Fig. 19-3: A simple FM System

7. Figure 3 illustrates a simple mechanical frequency modulator similar in principle to that used in the FM Radar System. The grid RF oscillating circuit shown in this case largely determines the operating frequency of the oscillator. It is evident if any change is made in the value of capacity across the coil the operating radio frequency will be varied accordingly. A condenser microphone or similar device is connected across the oscillatory circuit. Such a microphone is essentially a variable condenser, one plate being fixed, the other, a thin metal diaphragm, free to vibrate in response to sound waves. Sound wave compressions will force the diaphragm closer to the stationary plate, thus increasing the capacity across the coil and lowering the radio frequency.

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Rarefactions, on the other hand, will force the diaphragm outward, lowering the circuit capacity and increasing the radio frequency. It follows that the greater the amplitude of the sound waves, the greater will be the RF oscillator frequency swing and the rate at which these frequency swings occur will correspond to frequency of the audio waves.

8. Having impressed the desired intelligence (AF in this case) on the carrier by means of FM, the problem arises at the receiver of separating that intelligence from the RF carrier. Before considering any form of Balanced Detector, a very simple type of frequency detection will be examined.

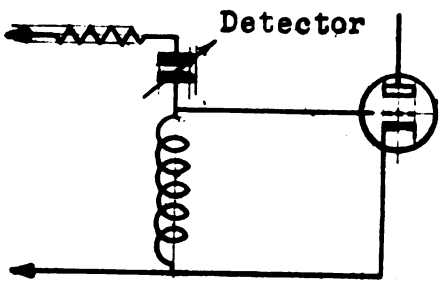

Fig. 19-4: A Simple FM Detector.

9. The simplest device for converting frequency variations into amplitude variations is an "off tune" resonant circuit, shown in Figure 4.

10. The response curve of a simple FM Detector is shown in Figure 5. With the carrier tuned in at point "A" a certain amount of RF voltage will be developed across the tuned circuit, and, as the frequency is varied on either side of this frequency by the modulation, the RF voltage will increase or decrease to points "C" and "B" in accordance with the modulation. If the voltage across the resonant circuit is applied to an ordinary detector as in Figure 4 the detector output will vary in accordance with the modulation, the amplitude of the variations being proportional to the deviation of the signal, and the rate being equal to the modulation frequency.

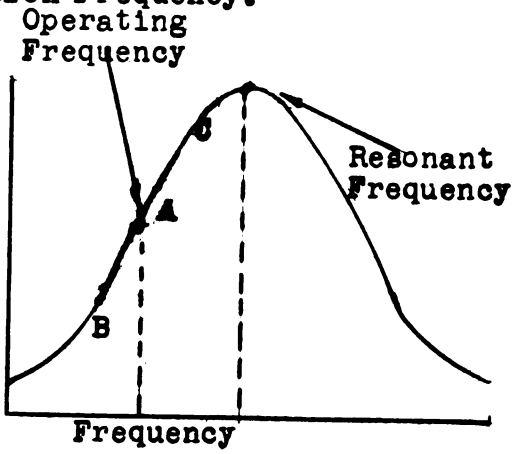

Fig. 19-5: A frequency Response Curve of an LC Circuit.

It is evident from Figure 5 that only a small portion of the resonance curve is usable for linear conversion of frequency variations into amplitude variations, since the linear portion of the curve is rather short. In addition to this disadvantage the detector is not balanced, i.e., only one rectifier is used, consequently the output will be dependent upon the signal level as well as the frequency. As a result such a circuit will be susceptible to noise modulation of the carrier which may succeed in getting through the limiter. For these reasons this type of frequency detection is seldom used, the various forms of Balanced Detectors being much more satisfactory.

11. Limiters in FM: Most FM detectors are preceded by one or more limiter stages. This part of the FM receiver is not found in the ordinary broadcast receiver. The limiter associated with the FM detector serves to remove amplitude modulation and pass on to the Balanced Detector a frequency modulated signal of constant amplitude (see Chapter XII, LIMITERS). Up to a certain

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point the output of the limiter will increase with an increase in signal. Above this point, however, the limiter becomes overloaded, and further large increases in signal will not produce any increase in output. To operate successfully, the limiter must be supplied with a signal of high amplitude, so that the amplitude of its output will not change for fairly wide variations in signal strength. Noise, which causes little frequency modulation but considerable amplitude modulation of the received signal is virtually eliminated in the limiter stage. This in part accounts for the superiority of FM performance.

12. The Travis Discriminator: The first type of Balanced Detector to be discussed is often called the Travis Discriminator. The word, discriminator is associated with some Balanced detectors because it discriminates between signals of different frequencies.

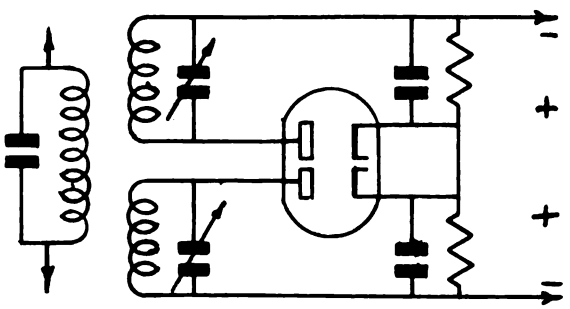

Fig. 19-6: The Travis Discriminator.

13. In the discriminator shown in Figure 6 two tuned circuits are used, one being tuned on each side of the IF amplifier frequency, and with their resonant frequencies spaced slightly more than the expected transmitter "swing apart". Obviously as the frequency varies on either side of resonance a greater signal will be applied to one diode than the other enabling the one to produce a greater DC voltage than the other. If both signals are equal, as is the case at the "center" frequency, the DC output will be zero volts, since the two series voltages are equal and opposite. If the voltage impressed on the upper diode is greater than that impressed on the lower diode the output of the discriminator will be negative, if less, the output will be positive. Thus the voltage appearing across the series load resistances will be an audio voltage corresponding to the FM signal modulation, and may be applied to an audio amplifier. The Travis Discriminator like other Balanced Detectors cancels or balances out undesirable amplitude modulation at its center of "balanced" frequency. This is true since at that frequency the changes in amplitude are applied equally to both tubes resulting in equal increases or decreases of the opposing voltages across the load resistances, but since these voltages are equal and opposite, they will at all times cancel out. However, as the frequency swings away from the balance point this relation no longer holds true, hence the necessity for a limiter stage preceding the Balanced Detector to insure that all amplitude variations are clipped from the FM carrier. This type of discriminator was used extensively at one time but being difficult to align has lost preference in favor of the phase shift type discriminator. (Foster-Seeley)

14. The Foster-Seeley Discriminator: The analysis of the discriminator shown in Figure 7 is as follows: With the applied frequency some value to which both primary and secondary are resonant, the voltage appearing across the secondary (E_1 plus E_2) will be 90 degrees out of phase with the primary voltage E_p. This follows from the fact that the secondary at resonance reflects only a resistance to the primary.

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Consequently the current through the primary inductance will be 90 degrees out of phase with the applied voltage.

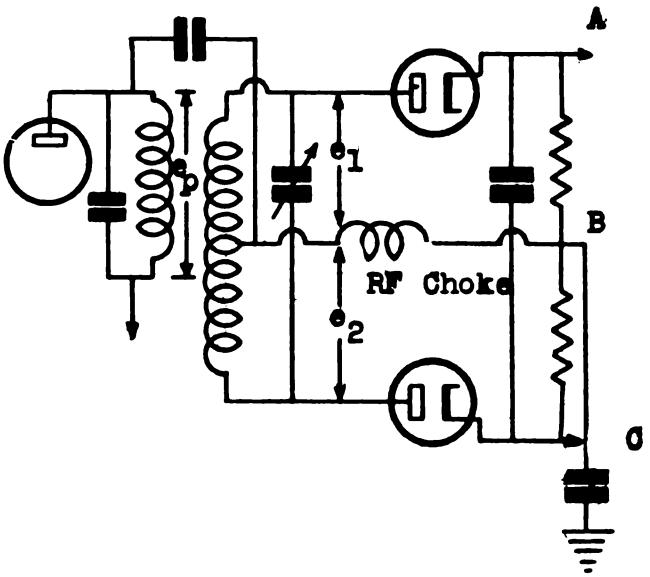

Fig. 19-7: The Foster-Seeley Discriminator.

The induced voltage in the secondary circuit isagain 90 degrees out of phase with the primary current, and finally the voltage across the secondary tuning capacity is 90 degrees out of phase with the secondary current, which is in phase with the induced voltage. The resultant of these four relationships is a total shift of 90 degrees between primary and secondary voltage at resonance.

15. Since one side of the primary is connected to the center of the secondary, the primary voltage acts in series with one-half of the secondary voltage on one diode, and in series with the other half on the other diode. Thus the resultant voltage on each diode is the vector sum of two voltages in phase quadrature at resonance. On one diode the secondary voltage leads the primary voltage by 90 degrees as viewed from the diode, on the other it lags. If we assume, for the purpose of illustration, that the primary voltage equals the total secondary voltage, the voltage on each diode at resonance would then be approximately 1.12 times the primary voltage (square root of the sum of the squares of V_p and $V_p/2$).

16. As the frequency departs from resonance the secondary voltage also departs from this 90-degree phase relationship with the primary, approaching either zero or 180-degree phase shift with respect to the primary applied voltage, depending upon which way the frequency shifts. In this event the voltage in one half of the secondary will approach an in-phase relation with the primary voltage while the voltage of the other half approaches phase opposition. If carried far enough one-half of the secondary would ultimately be directly additive to the primary, whereupon the voltage applied to that diode would be $1.50V_p$, while the other diode would have $.50V_p$ applied to it. Another factor enters here however, in that the primary voltage falls off as the frequency varies from the resonant point. As a result the voltage applied to one diode will increase at first as the frequency is changed due to the phases of the two component voltages approaching equality, reaching a peak value, then will decrease as the frequency is changed further. Simultaneously the voltage across the other diode will be decreasing, consequently the DC voltage across the two diode leads connected in series will vary through zero to plus or minus as the frequency is varied, developing an audio voltage corresponding to the modulation which is passed on to the amplifier stage. This type of discriminator has the highest degree of sensitivity since the output is obtained as the difference between two equal and quite large voltages, so that relatively small variations in these voltages result in considerable outputs. Also, since the output at balance is zero this system is not res-

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ponsive to amplitude modulated noise when no modulation is present. Bear in mind, however, that when modulation occurs the frequency swings away from the balance point, and then the output depends upon the amplitude as well as the frequency of the applied signal. Unless a limiter system is used, amplitude (noise) modulation will make its presence known.

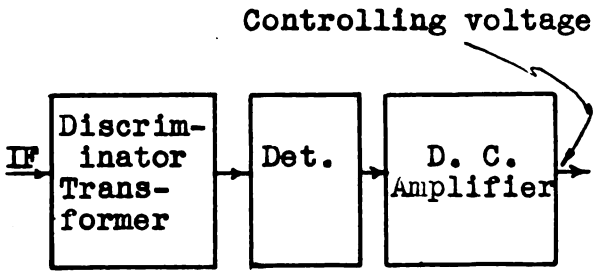

Fig. 19-8: AFC Block Diagram.

17. Automatic Frequency Control: One of the most important applications of the discriminator type of Balanced Detector in RADAR at present is that of Automatic Frequency Control (AFC). In microwave Radar equipments a superhetrodyne type of receiver is employed. To operate at its maximum sensitivity the frequency difference between received signal and local oscillator must remain constant otherwise the beat frequency produced will not be the same as that to which the IF amplifier stages are tuned. The local oscillator used in these equipments is usually one employing the Klystron principle. (See Chapter IX). Its frequency of operation can be varied to some extent by changing the voltage applied to its repeller element. A Balanced Detector is employed to make use of this property of the Klystron. This detector is an addition to the circuit and does not replace the normal superhetrodyne detectors. It is supplied with part of the output signal from the IF stages and is so tuned and adjusted that no output voltage is produced as long as the signal fed to it is "on" the IF frequency. In other words it is balanced at that frequency. If, however, the frequency of either the transmitter (which determines the frequency of the return echo signal) or the Klystron local oscillator in the receiver tends to drift, the Balanced Detector is no longer balanced and produces a DC voltage at its output, the polarity of this voltage depending on the direction of frequency drift. This DC voltage is amplified by a DC amplifier and in turn applied to the repeller of the Klystron. Its polarity and amplitude is so adjusted that it exercises just sufficient control to bring the Klystron to whatever frequency is required to maintain the correct frequency difference between the local oscillator and the transmitter. Thus it is possible to compensate within limits for frequency drift of either the transmitter or the local oscillator.

18. Balanced Detectors in Frequency Modulation Radars: In the frequency-modulation Radar system, the carrier frequency of the RF energy is continuously varied, in periodic fashion, swinging from a high frequency to a low frequency and back again at a rapid rate. Since there is a finite delay between the transmission of the RF energy and its reception from the target, the received signal in general has a different carrier frequency from that then being transmitted. The frequency difference, moreover, is proportional to the time required for transmission to and reflection from the target. In the receiver, the two carrier frequencies are combined and the beat frequency between them is detected. The presence of the beat note reveals the presence of the target, and the frequency of the beat note indicates the time difference between the transmission and reception.

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19. The FM Radar Balanced Detector: To detect the instantaneous beat frequency produced by the two frequency modulated signals, one transmitted earlier and now being received as an echo at the instant that the other is being transmitted, a special type of Balanced Detector is employed. An approximately equivalent circuit of this detector using lumped constants is shown in Figure 9. Details of the operation of this circuit will be taken up in the study of the Absolute Altimeter. This detector, in common with the other types of Balanced Detectors, is "balanced" to minimize undesirable amplitude modulation.

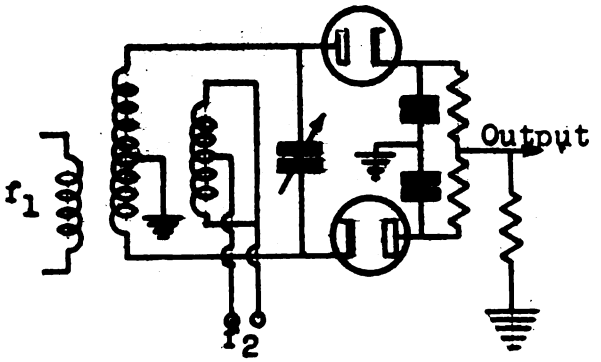

Fig. 19-9: The FM Radar Balanced Detector.

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CHAPTER XX

COUNTING CIRCUITS

1. A counting circuit is one which receives uniform pulses, representing units to be counted, and produces a voltage in proportion to their frequency.

2. In several instances in Radar equipment it is necessary to control a circuit by a change in the frequency of the input voltage to that circuit. For instance, it might be desirable to operate some indicating device, such as a meter, so that a change in frequency of the signal applied would cause a change in the reading on the meter. In this case a counting circuit which could respond to a change in the number of pulses per unit of time would perform the required action.

3. In addition to causing a change in a voltage level for a change in frequency the counting circuit, with a few changes, can be made to supply a triggering voltage to some sensitive circuit, such as a blocking oscillator, at a submultiple of the frequency of the pulses applied to its input. This is quite useful in equipment where it is desired to operate one part of the circuit at a fundamental frequency and another part at a subharmonic of that frequency.

POSITIVE OR NEGATIVE COUNTING

4. Positive Counting: The primary requirement in a counting circuit is that all the pulses entering the counting diode be of the same amplitude and time duration. If these requirements are not met then the effect which each pulse will have on the circuit will be different and the purpose of the counter will not be accomplished. In this chapter the shaping and limiting to equal amplitudes of the pulses will not be covered, since the explanations of limiting and differentiating are to be found elsewhere in this manual. (See Chapters III and XII) Suffice it to say that the pulses arriving at the counter are the same in all respects, regardless of a change in frequency.

5. In Figure 1, if positive pulses are applied to the plate of diode V_1 a current flow will result through its cathode load resistance and from cathode to plate.

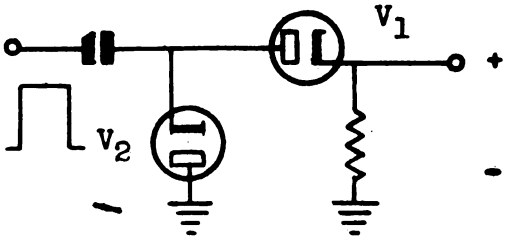

Fig. 10-1: Positive Counter.

Considering one cycle of operation, since the leading edge of the pulse is going positive the diode V_1 will conduct and current will flow through the resistance. Thus the coupling condenser becomes slightly charged due to the fact that electrons were removed from one plate and added to the other. Now the trailing edge of the pulse causes the diode V_2 to conduct (since the negative going voltage on its cathode acts in the same manner as would a positive voltage on its plate) and

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the condenser is discharged from its slightly charged condition. This second diode is necessary to keep the condenser from charging up to a value where a positive pulse would cause no effect on diode V_1.

6. Referring to Figure 1, it is apparent that since a certain amount of current flows through the load resistance and diode V_1 each time a pulse is applied, an average current flows which will increase as the frequency increases, and vice versa. The IR drop across the load resistor is of such a polarity that the top of the resistance is positive with respect to ground. This voltage can be used to control a following circuit such as is shown in Figure 2. The filter in the grid circuit will aid in obtaining smooth operation and freedom from too rapid changes.

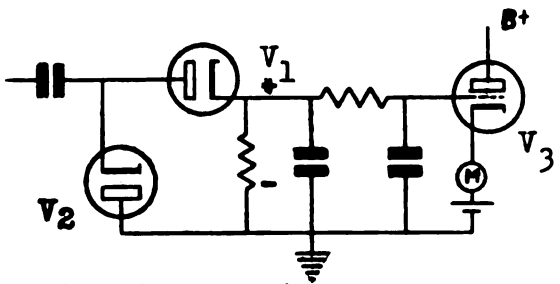

Fig. 20-2: Circuit Controlled By Positive Counter.

The voltage from the counter circuit willrise with an increase in frequency, causing the controlled tube V_3 to draw more current. If some indicating device, such as a meter, is inserted in the tube circuit so that the tube's current flows through it also, then a direct indication will be given every time a change in frequency occurs at the input. It should be realized at this point that the system just described is useful for detecting slow changes in frequency and not rapid variations which could not be followed by a meter.

7. Negative Counting: By simply reversing the connections to the two diodes in Figure 1, the counter can be made to respond to the negative going pulses. This then will produce an opposite effect on the circuit as shown in Figure 3.

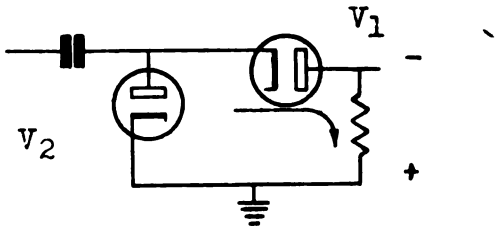

Fig. 20-3: Negative Counter.

That is, an increase in frequency will still cause an increase in average diode current but the current flow will be in such a direction as to make the top of the resistance negative with respect to ground. This would cause the current in a controlled tube to decrease with an increase in frequency giving an opposite indication to that of positive counting.

STEP BY STEP COUNTING

8. The step by step method of counting is similar to that already discussed except that no load resistor for the diode is used and a condenser is inserted in its place. In operation, pulses are applied, as shown in Figure 4, causing the diode V_1 to conduct.

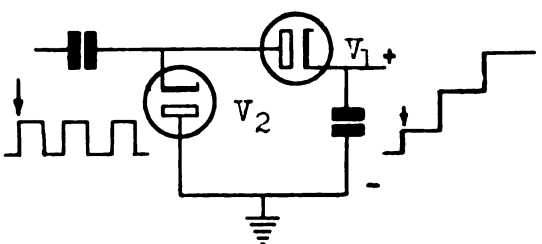

Fig. 20-4: Step by Step Counter

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Each time the diode conducts it increases slightly the charge on the condenser in its cathode circuit. The conducting diode removes electrons from the condenser plate which is tied to the cathode so that the step by step waveform as shown in Figure 4 appears at the cathode. The condenser is actually charged up in steps since there is no path present through which it can be discharged between pulses. Now if the circuit were left as it is in Figure 4, as soon as the cathode condenser reaches a charge equal to the amplitude of the input pulse the diode would cease to conduct since the voltage on the cathode would equal to the voltage appearing on the plate.

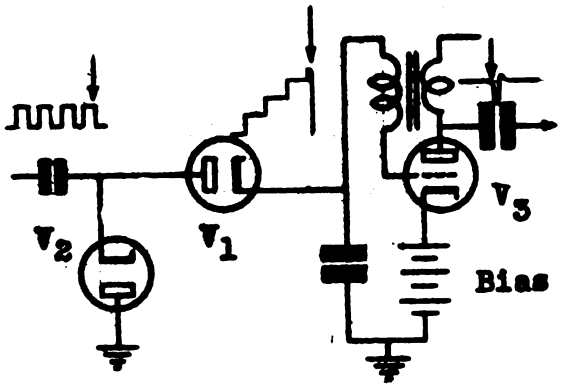

Fig. 20-5: Blocking Oscillator Triggered by Counter.

9. If a sensitive circuit, such as the single cycle blocking oscillator, shown in Figure 5, is connected to the output of the counter it can be triggered or "kicked off" when the voltage across the cathode condenser reaches the correct value. Thus the counter may have a frequency of 1000 cycles applied to its input and the blocking oscillator may be triggered at one fourth (250 cycles) of that frequency or at any other subharmonic. The particular step of the output voltage which triggers the oscillator may be determined by adjusting the bias on the cathode of the oscillator tube so that more or less steps, which is to say, fundamental frequency pulses, may be required to trigger the circuit. When the oscillator does start its cycle of operation the grid is driven positive so that the grid current which flows quickly discharges the counter circuit condenser. (See Chapter V) It is then ready to be recharged in steps to trigger off the oscillator again.

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APPENDIX A

Dictionary of Classified Terms

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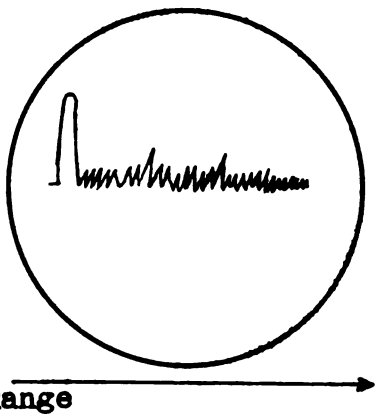
APPENDIX A

DICTIONARY OF CLASSIFIED TERMS

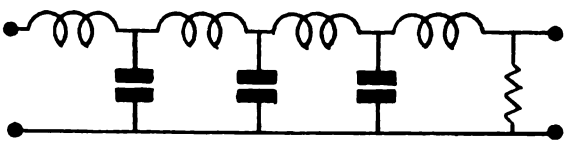
'A' INDICATOR: A type of RADAR Indicator in which the sweep wave is applied to the horizontal deflecting elements of a cathode ray tube having a short persistance screen. The signal from the reflecting object is applied to the vertical plates. The range of the reflecting object can be measured in terms of the distance from the start of the sweep, or from a permanent blip caused by the transmitted pulse, to a signal blip, caused by the echo.



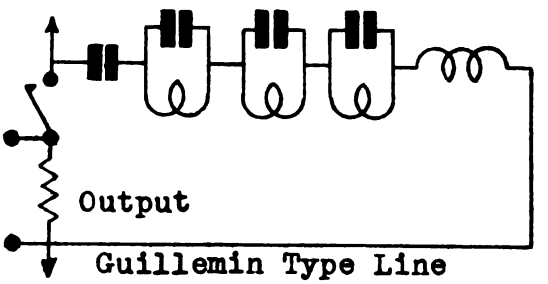
ANTI-HUNT CIRCUIT: A circuit in which a portion of the output voltage of an amplidyne generator (mechanical amplifier), which is used to drive a rotating antenna system, is fed back into the input circuit in such phase and magnitude as to prevent the antenna from oscillating about any position.

ANTI-TR BOX: Part of the duplexing system in certain RADAR equipments which presents high impedance to the return signal looking toward the RF oscillator.

ARTIFICIAL TRANSMISSION LINE: A network composed of lumped constants which can be used to introduce a time-delay or to form an accurately timed pulse. It is similar to an ordinary transmission line with its own inductance and distributed capacity. Sometimes called pulse forming network or delay line.



Artificial Line



Guillemin Type Line

AUTOMATIC GAIN STABILIZATION: A circuit used in certain IFF equipments and in certain RADAR beacon systems which serves to maintain optimum sensitivity of the superregenerative receiver tube. The gain of the tube is controlled so that noise pulses, characteristic of a superregenerative receiver, are held to a constant level, yet permitting good response to weak received signals. The system thus prevents random noises from triggering the automatic transmitter associated with the receiver.

BALANCED DETECTOR: A circuit useful for detecting changes in frequency or phase rather than changes in amplitude. The difference in tube load current in the useful feature of the circuit. The load current flowing in each tube is in propor-

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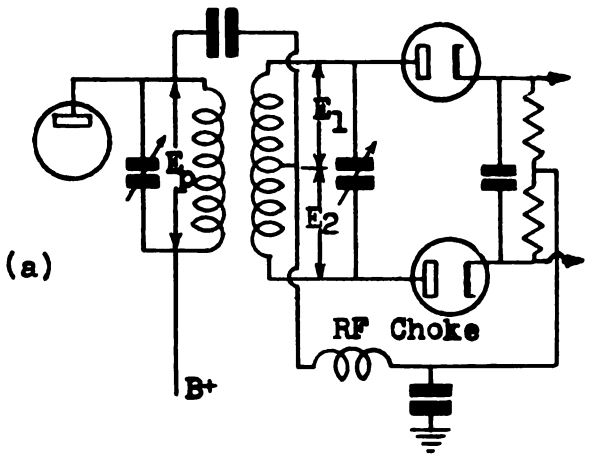
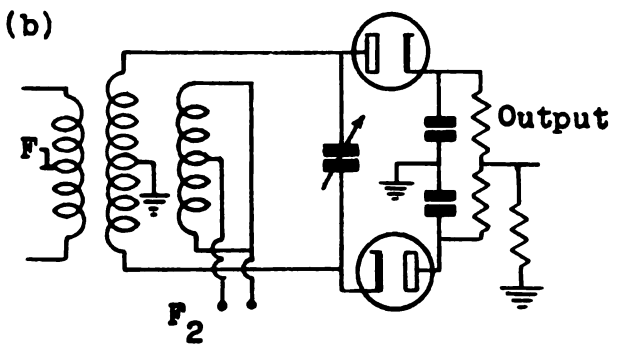
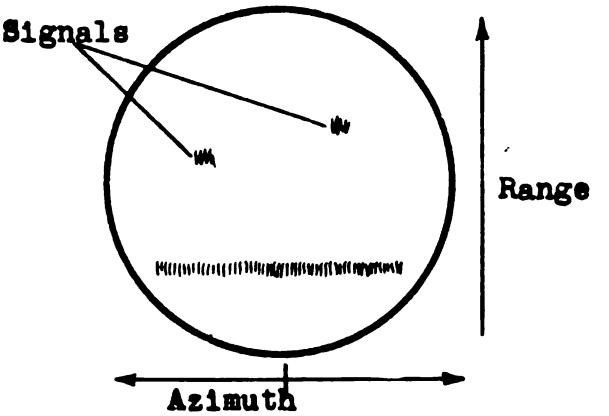
tion to the magnitude of the resultant voltage on that tube. Fig. (a) is designed to detect the beat produced by mixing two varying frequencies at the input. Fig. (b) is commonly preceded by a limiter stage to remove any amplitude modulated component and when so operated is usually called a discriminator (particularly for automatic frequency control circuits).





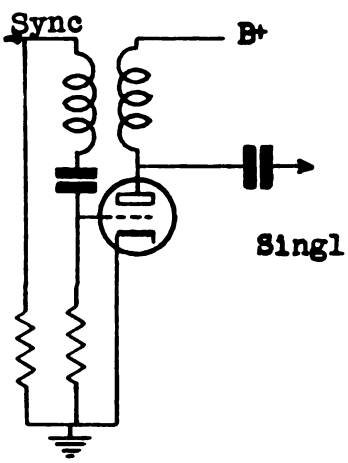
BASE OSCILLATOR: See REPETITION RATE OSCILLATOR.

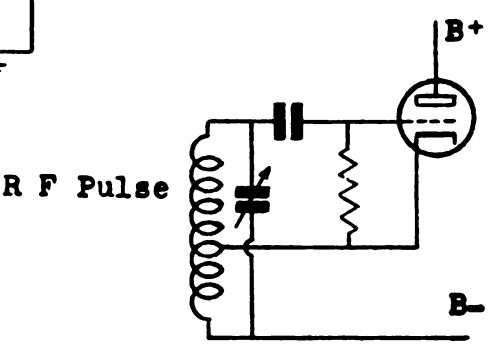
'B' INDICATOR: A type of RADAR indicator in which azimuth is presented as a horizontal deflection of the cathode ray beam and range as a vertical deflection. This is accomplished by applying a sawtooth wave to the vertical deflection elements of the cathode ray tube, and connecting the horizontal deflecting elements to the output of a potentiometer which is arranged to turn with the horizontal motion of the antenna. The vertical scanning begins as the pulse is transmitted. When an echo signal is received the output of the receiver intensity-modulates the grid or cathode of the cathode ray tube, causing a bright spot to appear on the tube screen. The horizontal position of this spot corresponds to the azimuth of the target, and the distance vertically above the base line shows the range. The indicator brilliance can be turned down so that the trace lines do not appear, while the bright spots caused by echoes are clearly visible.



BLANKING VOLTAGE: See INDICATOR GATING.

BLOCKING OSCILLATOR: An oscillator running freely or controlled by a synchronizing voltage, which cuts itself off after one or more cycles by the flow of grid current charging the grid capacitor.





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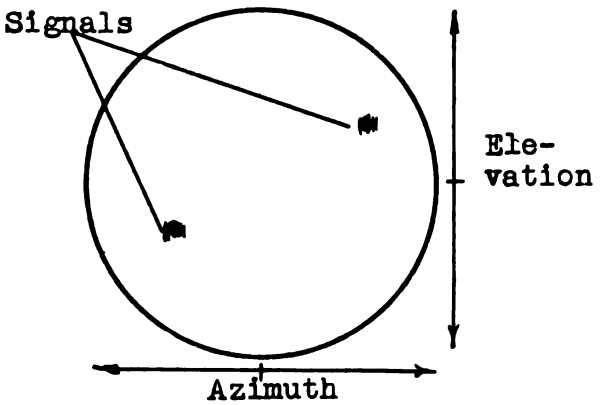
BUNCHER: An input resonant cavity which forms a part of the conventional Klystron oscillator (not reflex Klystron). See KLYSTRON.

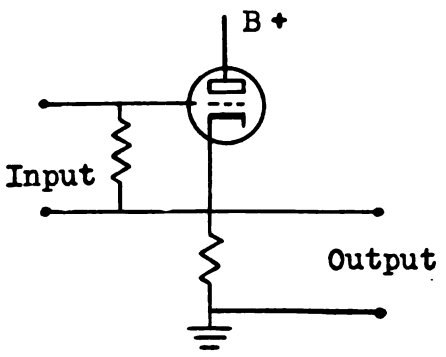
'C' INDICATOR: A type of RADAR indicator which shows the target signal as a bright spot with azimuth plotted horizontally and elevation plotted vertically. No indication of range is given in this type of picture.



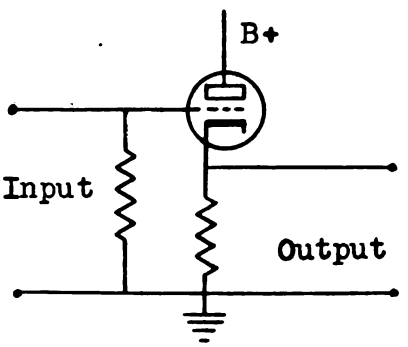
CALIBRATION MARKER: See RANGE MARKER.

CATCHER: The second, or output, resonant cavity in the conventional Klystron oscillator (not reflex Klystron). See KLYSTRON.

CATHODE COUPLED AMPLIFIER: An amplifier with its load impedance in the low voltage (to ground) side of the circuit rather than in the plate or high voltage part of the circuit. Its input is between grid and cathode instead of between grid and ground as in a cathode follower. It amplifies the input wave without inverting its polarity.



CATHODE FOLLOWER: A degenerative vacuum tube circuit in which degeneration is produced by an unbypassed cathode resistor the output being taken across this resistor. This circuit is essentially an impedance matching device with less than unity voltage gain but possessing some power gain. The high input impedance and very low output impedance render it particularly suitable for coupling between pulse generating or pulse transmitting stages and transmission lines or circuits whose shunt capacities might otherwise cause objectionable effects. The output of a cathode follower is of the same polarity, and therefore 'follows' the input grid voltage.



CAVITY RESONATOR: See RESONANT CAVITY

CENTERING DIODE: A clamping circuit used in some types of PPI indicators. (See CLAMPING).

CENTIMETER LOCAL OSCILLATOR: Any of several types of reflex Klystrons or lighthouse tubes used as RF or IF conversion oscillators.

CENTIMETER MIXER: A circuit for mixing the centimeter local oscillator signal with the return echo signal to produce the intermediate frequency (including grounded grid triodes and crystal mixers).

CIRCULAR (TIME BASE) SWEEP: A circular sweep obtained on the screen of a CRT by the application

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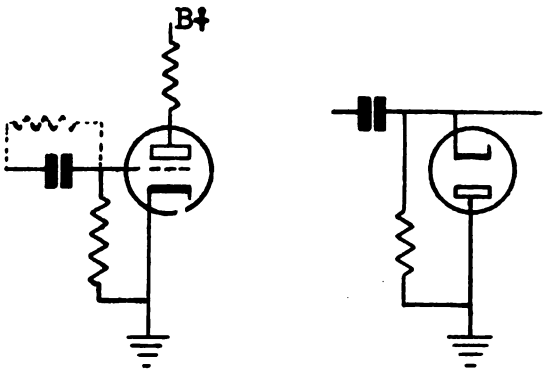
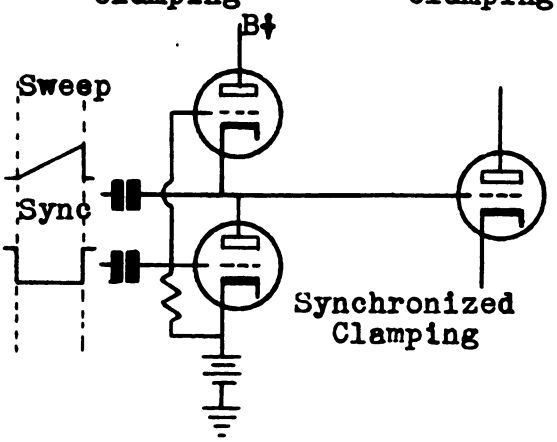
of two sinusoidal voltages, 90 degrees out of phase, to two sets of deflecting plates. The signal may be used to amplitude modulate or deflect the CRT beam to give the desired indication.

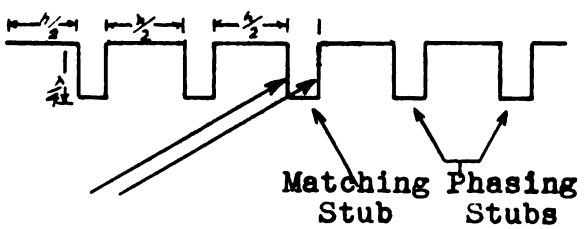
CLAMPING: A circuit which clamps either amplitude extreme of a waveform to a given reference level of potential.



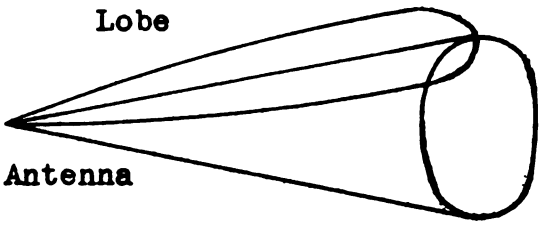


CLIPPER: See LIMITER.

COLINEAR ARRAY: An antenna having a series of half wave elements excited in phase



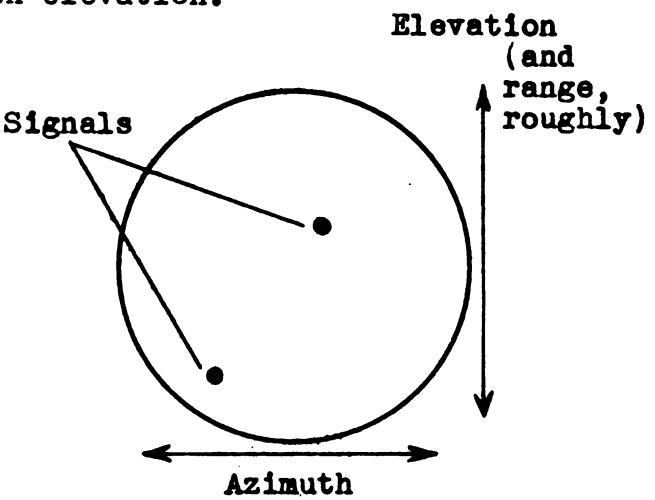
CONICAL SCAN: A type of scanning in which the antenna lobe is made to describe a conical revolution. This may be used with a PPI type scope but does not give a PPI indication.



CONTROL CENTRAL: In RADAR, a generic term for a combination of circuits and associated equipment in one unit providing the following: triggering pulses, sweep circuits, intensifier pulses, gating voltages, blanking voltages, and power supplies.

COUNTER CIRCUIT: A circuit which receives uniform pulses representing units to be counted and produces a voltage in proportion to their frequency.

'D' INDICATOR: A type of RADAR indicator which combines type B and C pictures. The signal appears as a bright spot (intensity modulated) with azimuth plotted horizontally and elevation plotted vertically. Range is also approximated, being plotted vertically with elevation.



DCR (DIRECT CURRENT RESTORATION): See CLAMPING CIRCUIT.

DC AMPLIFIER: A type of amplifier used for amplifying direct current or voltage, usually containing frequencies not in excess of a few cycles per second, i.e., so low that it is necessary to design the

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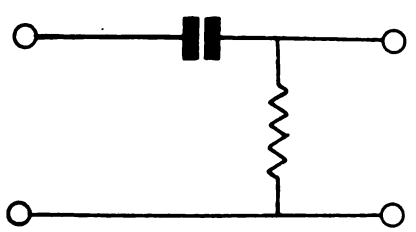
amplifier to respond to zero frequency also.

DECOUPLER: A part of the duplexing assembly used in RADAR equipment. The decoupler is used to decouple the transmitter from the receiver when the former is in operation. A decoupler together with a REPROD, forms a DUPLEXER.

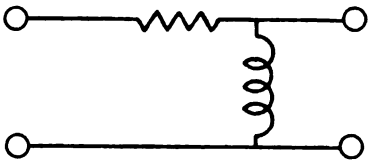
DF (DIRECTION FINDING): Generally refers to radio direction finders. It is also used sometimes by the British for RADAR instead of RDF. Sometimes written D/F.

DIFFERENTIATING AMPLIFIER: A distorting amplifier, commonly used in pulse systems, the function of which is to form short narrow pulses from more extended rectangular waves. The differentiating amplifier is essentially a capacitively coupled video amplifier, employing an RC or LR differentiator in either its grid or plate circuit. Sometimes called a sharpening or shaping amplifier.

DIFFERENTIATOR: A circuit which produces an output voltage substantially in proportion to the rate of change of the input voltage or current. Differentiating circuits employ very short time constants compared to the time duration of the pulse.



RC Differentiator



L/R Differentiator

DIPLEXER: A coupling system which allows a RADAR and a communication transmitter to operate simultaneously or separately from the same antenna - not to be confused with the DUPLEXER.

DISCRIMINATOR: The combination of a tuned circuit and detector for a demodulation of frequency modulated waves. (See BALANCED DETECTOR).

DRIVER: A circuit which, when triggered, is designed to drive a modulator with a rectangular pulse of accurately timed width.

DUPLEXER: In RADAR - the circuit element which effects a mismatch in the receiver transmission line when the RF oscillator is firing, and which restores matching to the receiver transmission line during the period that the oscillator is at rest. The function of the circuit is to prevent overloading of the receiver by the transmitted pulses. (See TR BOX, TR CAVITY ANTI-TR BOX, REPROD, AND DECOUPLER).

DUTY CYCLE: The percentage of the total time of a complete cycle which is represented by the transmitted pulse. For example, a 2 u.sec. pulse, repetition rate of 500 cycles, the time of one cycle is 2000 u.sec. and the duty cycle is 2/2000 or .1%.

'E INDICATOR: A modification of type 'B' INDICATOR. The signal appears as a bright spot with range plotted horizontally and elevation plotted vertically.

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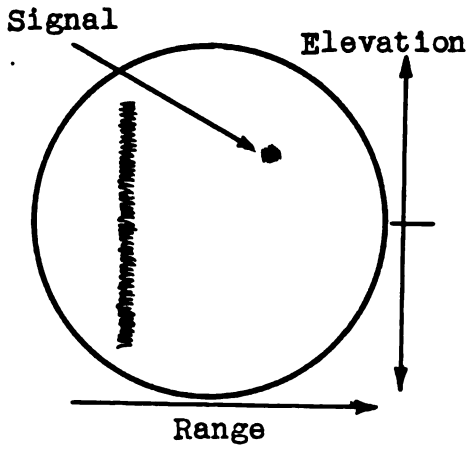
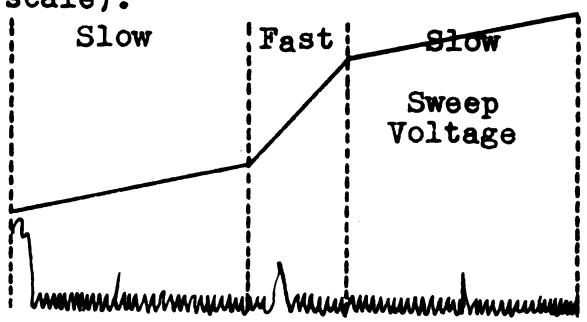


ECCENTRIC TUNER: A variable impedance transformer for matching the impedance of the RF oscillator to the impedance of the transmission line. There are two adjustments, one for impedance matching and one for presenting a reactive component to balance out the reactive component of the RF oscillator. The tuner is often called an IMPEDANCE TRANSFORMER.

ECHO: The reflected RF pulse which returns to the transmission point.

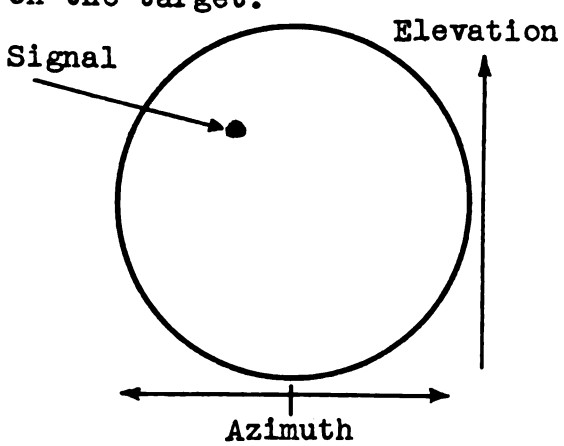
ECHO SPLITTING: In certain RADAR equipments, the echo return is split, and appears as a double indication on the screen of the RADAR indicator. This splitting is accomplished by special electronic circuits, associated with the antenna lobe switching mechanism. In use the antenna is rotated until the two echo indications are the same height, which indicates correct bearing. (See 'K' INDICATOR).

EXPANDED SWEEP: A type of sweep circuit in which the midportion of the trace is made more rapidly than the trace at the two extremities. Because the trace is more rapid in the midportion section, signals occurring at a fixed periodic rate and applied to the signal plates will appear spaced farther apart in that portion of the sweep than at the ends, hence the midportion section is said to be 'expanded'. Expanded sweep permits taking precise readings without limiting the total range coverage shown on the screen of the indicator. (Note: the term 'expanded sweep' may also, in some cases, be applied to systems in which the length of time required for the visible trace is decreased, without providing for expansion of the midportion of the scale).



Type of Scan Produced

'F' INDICATOR: A type of RADAR indicator in which a single signal, only, appears as a bright spot. Azimuth angle error is plotted horizontally and elevation angle error is plotted vertically. Cross hairs on the indicator face permit bringing the system to bear on the target.



FLYBACK: See RETRACE.

'G' INDICATOR: A type of RADAR indicator in which a single signal, only, appears as a bright spot subtended by wings, which grow as the distance to the target is diminished. Azimuth angle is plotted horizontally and elevation is plotted vertically. (Referred to sometimes as 'Mark VI INDICATOR and as 'SPOT ERROR

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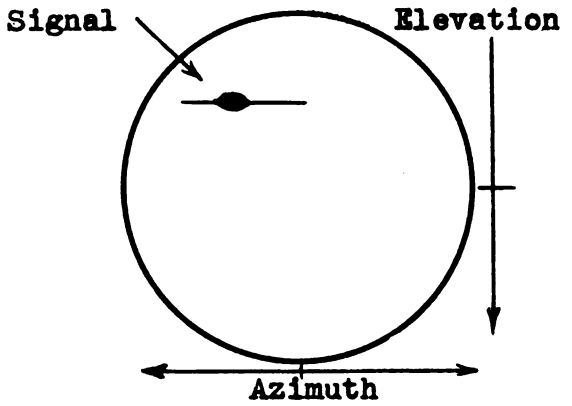
INDICATOR')



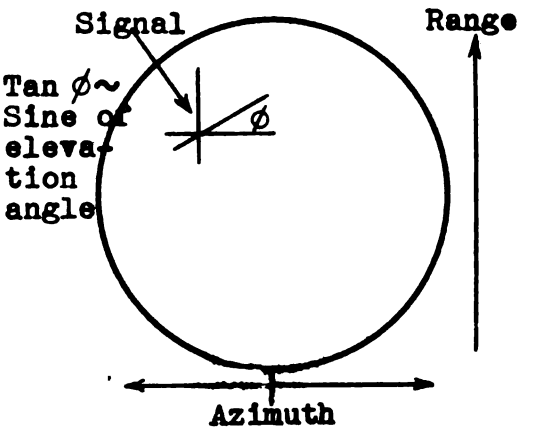
GATING OR GATE VOLTAGE: A pulse which is used to sensitize a circuit over that portion of the cycle during which operation is desired, or to desensitize that circuit over those portions of a cycle when operation is not desired. Also called BLANKING PULSE.

GHOST SIGNALS: Signals appearing on the screen of the RADAR indicator, the cause of which cannot readily be determined.

GRASS: Random interference caused primarily by circuit noises, such as thermal agitation. The interference appears as closely spaced, sharp pulses on the sweep of any amplitude modulated or deflection type scope picture. On an intensity modulated scope the interference will sometimes give a 'sandpaper' effect picture. If the equipment is operating properly the level of the 'grass' voltage will be substantially the same for the whole cycle, and not sufficiently great to cause bad interference to echoes from targets within range.

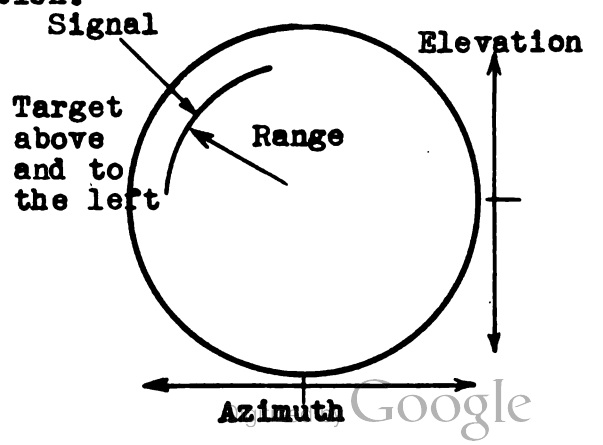
GRID PULSING: A circuit arrangement of the RF oscillator in which the grid of the oscillator is biased so negatively that no oscillation takes place even when full plate voltage is applied through the tube, and pulsing is accomplished by removing this negative bias through the application of a positive pulse on the grid.

'H' INDICATOR: A type of RADAR indicator which is a modification of type 'B' indication. The signal appears as a bright line, the slope of which is proportional to the sine of the angle of elevation. Azimuth is plotted horizontally with range plotted vertically.



HORN: A type of radiator, made in the shape of a horn and attached to a wave guide. Used to direct the radiation from a waveguide.

'I' INDICATOR: A type of RADAR indicator used to indicate range and direction with a conically scanning antenna. The signal appears as a bright circular segment with radius proportional to range. The circular length of the segment is inversely proportional to the error of aiming. The system and its position indicates the bearing of the target. True aim results in a complete circle. This referred to sometimes as RTB or broken circle indication.



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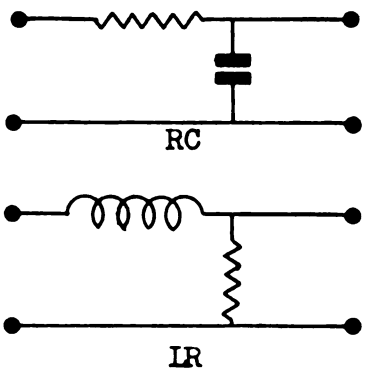
IFF(IDENTIFICATION, FRIEND OR FOE): Generic term applied to equipment used for recognition or identification of ships or aircraft detected by RADAR.

INDICATOR GATING: Applying a voltage to the grid or cathode circuit of an indicator cathode ray tube to sensitize or desensitize it during the desired portion of the operating cycle.

INITIAL PULSE: The transmitted pulse in RADAR. Also called DIRECT PULSE, MAIN BANG, etc.

INTEGRATING CIRCUIT: One which sums up, or produces an output voltage substantially in proportion to the frequency and amplitude of the input pulses.

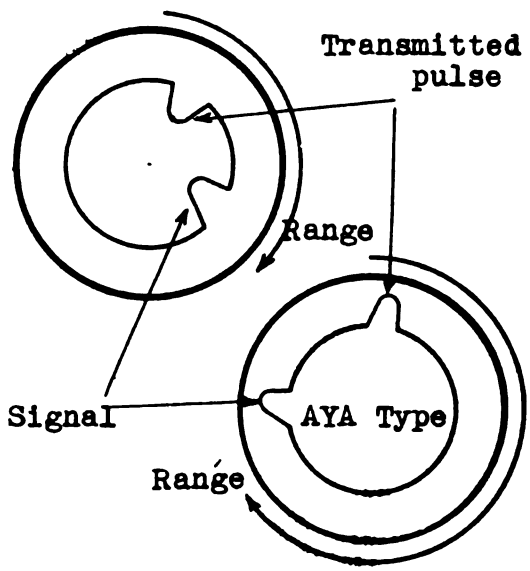


INTENSITY MODULATION: A method of signal indication on a cathode ray tube used in certain types of RADAR indicators, such as class B, C, PPI, etc. With intensity modulation, the grid or cathode of the CRT is connected to the output of the final video amplifier, so that the bias on the tube decreases when an acho signal is received. With the CRT ordinarily biased so that there is no visible trace, the decrease in bias results in the appearance of a bright spot on the screen which serves in lieu of an echo signal blip.

INTERROGATION SIGNAL: The signal sent out by an IFF interrogator to a ship or aircraft whose identity is unknown.

INTERROGATOR: A unit in the recognition system which consists of a transmitter and receiver operating on IFF frequencies and synchronized with some type of RADAR search equipment. The receiver is designed to receive the signal from the IFF equipment on the ship or plane interrogated and apply that signal to the RADAR indicator.

'J' INDICATOR: A type of RADAR indicator which is a modification of type 'A' indicator. The sweep provides a circular range scale near the circumference of the cathode ray tube. The signal appears as a radial deflection of the sweep. No bearing indication is given.



'K' INDICATOR: A modification of type 'A' indication, used for aiming a double lobe antenna system in azimuth or in elevation. When used for the former, a horizontal time sweep is displaced slightly in the direction of the antenna lobe in use. The signal appears as a double vertical deflection of the sweep with the ratio of the amplitudes indicative of the error in aiming. When used for aiming a double lobe antenna in elevation, a vertical time sweep is displaced

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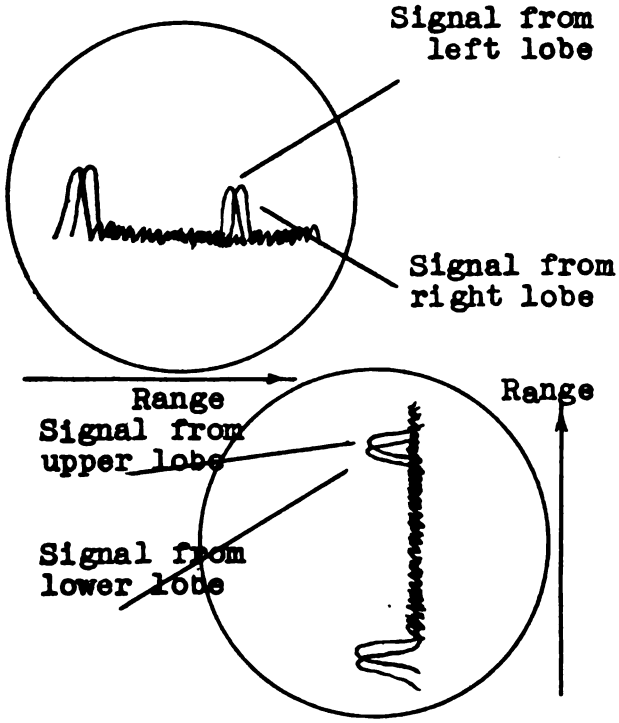
vertically slightly in the direction of the antenna in use, and the signal appears as a double horizontal deflection of the sweep with the ratio of the amplitudes indicative of the error of aiming. (See ECHO SPLITTING)



KLYSTRON (SPERRY GYROSCOPE COMPANY TRADE NAME): A type of oscillator or amplifier sometimes used in connection with reception of RADAR signals at microwave lengths. The Klystron is a device for converting DC energy into radio energy by alternately slowing down and speeding up an electron beam, utilizing the transit time between two points to produce an alternating current which delivers power to cavity resonator. The term Klystron is applicable to an ultra-high frequency amplifier or generator that uses the buncher principle, i.e., velocity modulation and drift distance, with one or more cavity resonators to produce and use a velocity modulated beam of electrons. An electron gun, similar to those in cathode ray tubes, furnishes a beam of electrons with a uniform average velocity beyond the anode plane or 'smoother grid'. A radio frequency field between the grids of the first resonator, usually called the 'buncher', modifies the velocity of the electrons passing these grids. The electrons which have been speeded up by the buncher overtake, in the drift space beyond the buncher, the electrons which left the buncher earlier but were slowed down during the previous half cycle. As a result, the beam current between the grids of the second or 'catcher' resonator is pulsating or bunched, and if the second resonator is tuned to the bunching frequency the beam will deliver power to the catcher. Coupling to the resonator is obtained with small wire loops which lead to the coaxial terminals, sometimes referred to as 'antenna seals'.

REFLEX KLYSTRON: In a reflex Klystron the operation is essentially the same except that the electrons which pass on through the second grid of the single cavity resonator are repelled by a plate with a negative potential on it so that the electrons make several trips backward and forward through the grids before they give up their power to one of the grids. The electrons must be repelled so that they arrive on the grids at the proper instant or in the proper phase relations to give aid to the oscillations. Thus the negative potential on the repeller plate can be varied to change the power output since if they do not arrive on the grid in proper phase relation the oscillations are not as strong. The cavity can be warped in some types of reflex Klystrons or may have variable tuning plugs in the cavity which are used for changing the frequency. The repeller plate voltage adjustment gives a vernier control of frequency for tuning. (See MCNALLY OSCILLATOR)

KNOCKER: A subassembly in RADAR equipment, comprising synchronizing and triggering circuits. The knocker is used to drive the

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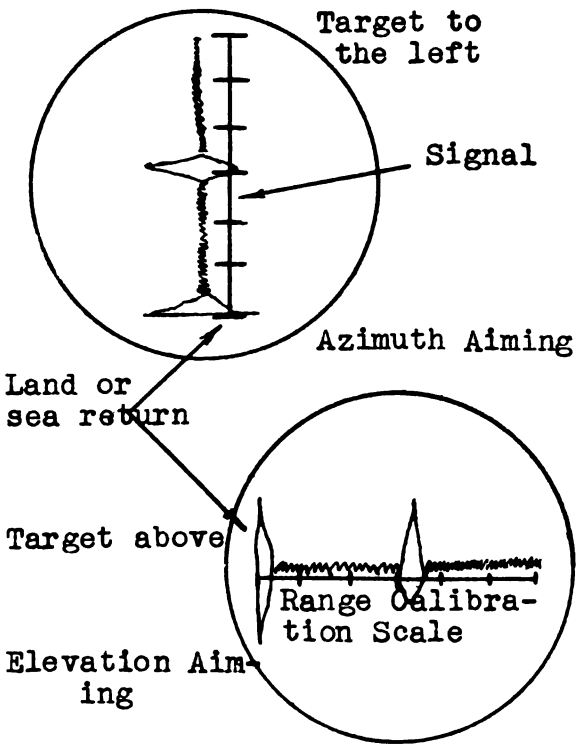
RF pulse generating equipment in the transmitter and to synchronize the cycle of operation in range units and range indicators with the transmitted pulse. Knockers generate steep sided pulses.

'L' INDICATOR (ASV, ASE, ASB): A type of RADAR indicator which is a modification of type 'A' indication, used for aiming a double lobe antenna system is azimuth or elevation. When used for azimuth aiming a vertical sweep indicates range. The signal from the left lobe appears as a horizontal deflection to the left, the signal from the right lobe appearing as a horizontal deflection to the right. The ratio of signal amplitude is indication of the error of aiming. When using for aiming a double lobe antenna system in elevation, a horizontal sweep is used for indicating error of aim.

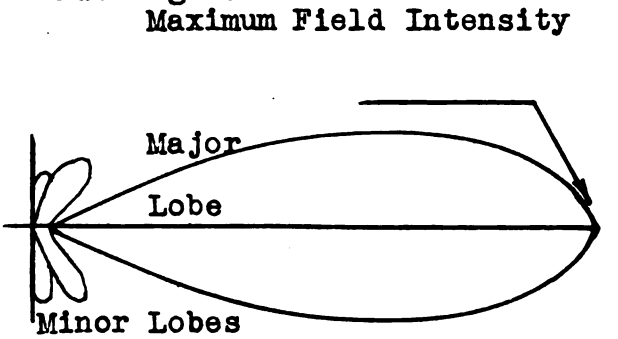


LAND RETURN: Deflection of the sweep or trace in a RADAR indicator, caused by reflection of transmitted pulses from the land.

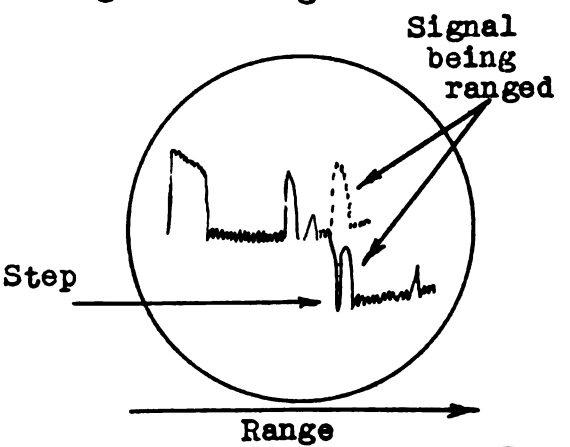
LAWNMOWER: A type of RF preamplifier used in conjunction with the receiver of the FC/FD RADARS, so called because use of the preamplifier cuts down on the level of the 'grass' on the indicator screen.

LIMITER: A circuit which limits or clips either or both the positive or negative portion of a waveform at a predetermined level.

LOBE (of an antenna): A two or three dimensional polar representation used to indicate the distribution in space of antenna field strength intensities. The field intensity at any given angle is in proportion to the radial distance from the point of origin to the curve of the lobe pattern at that angle.



'M' INDICATOR: A type of RADAR indication which is a modification of type 'A' indication, used for accurate range finding. A horizontal sweep is displaced vertically by a step voltage. The signal appears as a vertical deflection of the sweep. An auxiliary device for controlling the phase of the signal or the step is used to bring them into coincidence, at which point the device registers range.



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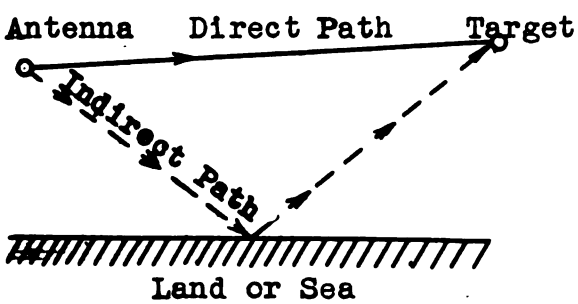
MAIN BANG: The transmitted pulse.

MAXIMA: (See MINIMA)

MCNALLY OSCILLATOR: A type of reflex Klystron requiring a single removable cavity resonator. Used in connection with RADAR reception at micro-wave-lengths. See KLYSTRON.

ME TYPE P INDICATOR: A type of Plan Position Indicator in which the deflection coils of the cathode ray tube are rotated mechanically (ASC, SG). In MM type P indicator, on the other hand, an electric field is used to generate the rotating magnetic field with stationary coils (ASG).

MINIMA: The region of minimum return from the transmitted pulse. This minimum return comes about because the radiated energy travels to and from the target along two paths, namely; (1) the direct, and (2) an indirect path in which the transmitted pulse strikes the land or sea and is reflected therefrom to the target. When the two waves reach the target out of phase, they tend to cancel each other out, and a minima is produced. When they reach the target in phase, the effect is additive, and a MAXIMA is produced.

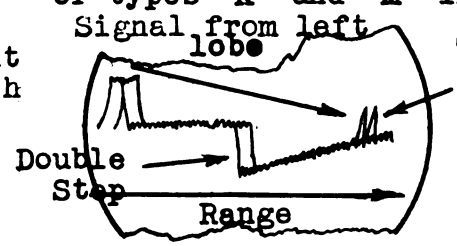


MODULATION GENERATOR: A unit of RADAR equipment in which the pulse originates, and in which harmonics of the pulse frequency are selected as range markers.

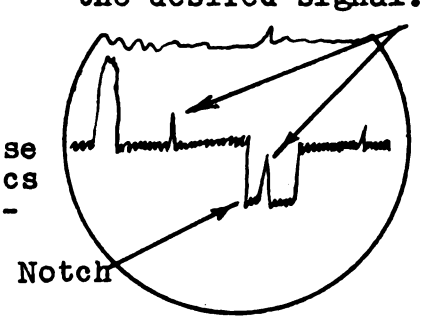
MODULATOR: In RADAR, the vacuum tube circuit which accomplishes the pulsing of the RF oscillator. No modulator is required if the transmitter is the self pulsed or blocking oscillator type.

MULTIVIBRATOR: A form of relaxation oscillator consisting of two resistance or resistance-capacity coupled amplifiers with the output of the second coupled back to the input of the first. The useful output is usually taken from the plate or cathode circuits of either one or both of the tubes. By varying the selection of circuit constants the multivibrator is capable of producing a wide variety of waveforms useful in Radar circuits, the most frequently used being square or rectangular waves. It can be synchronized or locked in step by a stable frequency source at its fundamental frequency or at a harmonic or subharmonic or that frequency.

'N' INDICATOR: A type of Radar indicator which is a combination of types 'K' and 'M' indicators.



NOTCH: A rectangular depression extending below the sweep line of the Radar indicator in some types of equipment. Echo signals are centered in the notch, thereby facilitating taking range and bearing reading. In addition the notch may be expanded to permit closer examination of the desired signal.



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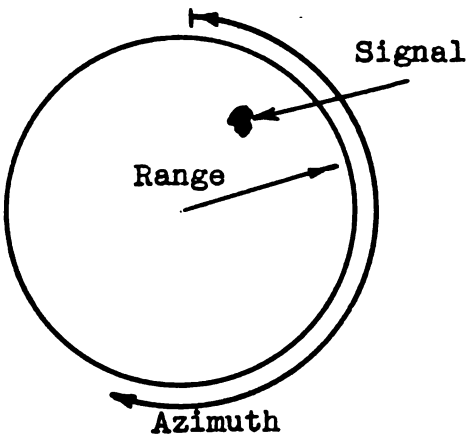
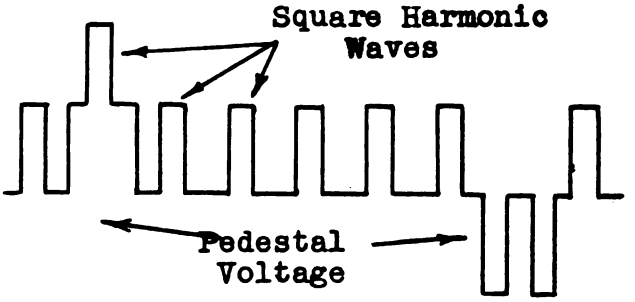
'O' INDICATOR: A type of RADAR indicator similar to type 'A' indication having a horizontal sweep and using a notch. (See illustration above)

'P' INDICATOR: A type of RADAR indicator which is used for plan position indication, and which plots range and azimuth in polar coordinates. The signal appears as a bright spot at a radial distance from the center of the screen which is proportional to range. The angular position of this signal on the screen corresponds to the azimuth angle of the target. The sweep starts from the center and sweep toward the edge of the tube as it is rotated either clockwise or counterclockwise.



PARAPHASE AMPLIFIER: An amplifier used to convert a single input to a push-pull output.

PEDESTAL: (1) A type of antenna support used in Model SC RADAR equipment. (2) The rectangular sweep voltage generated by circuits in the Model FC/FD indicator. In operation, the pedestal frequency is the same as the pulsing frequency. A rectangular harmonic wave is generated and superimposed on the pedestal wave with a periodicity corresponding to the pulsing rate. The resultant complex waveform is fed through a push-pull amplifier, the harmonic wave atop the pedestal being used on one side of the amplifier to trigger the sweep generator, and on the other side of the amplifier to form a notch.



PHANTOM SIGNALS: (See GHOST SIGNALS)

PHASE INVERTER: An amplifier employing degeneration and in some cases a voltage divider network in its grid circuit to invert the phase of a signal without changing its amplitude.

PHASE SHIFTING NETWORK: A combination of inductance, resistance or capacity which is used to produce an out of phase voltage with respect to a reference sine voltage.

PLAN POSITION INDICATOR (PPI): (See 'P' INDICATOR)

PLATE PULSING: A circuit arrangement of the RF oscillator in which the plate voltage is normally reduced to such a low value or completely removed, so that no current flows to the plate and no oscillations occur. A pulse equal to the full plate voltage is then introduced in series with the plate. Oscillations begin and last for the duration of the pulse. This circuit requires an amplifier capable of supplying full plate power. (See also GRID PULSING and SELF PULSING)

POLYPLEXER (Aircraft): A device for the combined operations of both duplexing and lobe switching in certain RADAR equipments. Use of a gas tube at the end of a quarter-wave line is made to protect the receiver from the transmitted pulse, and switches

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alternately connect the port and starboard antennas to the duplexing part of unit.

POLYROD ANTENNA: An antenna consisting of parallel rods, usually made of polystyrene. Used in Model FH (Mark 8) RADARS.

PULSE: An abrupt increase or decrease in voltage or current.

PULSE AMPLIFIER (VIDEO): A wide band amplifier capable of amplifying frequencies within and considerable above the audio frequency range. The band width might, for example, be from 30 cycles to 3 megacycles. Such wide band amplifiers are used in television and also in RADAR equipment.

PULSE CONTROLLED KEYER: A unit of IFF interrogator equipment, such as Model BL, which receives pulses from the RADAR unit and modulates the interrogator at the RADAR pulse recurrence frequency or at a submultiple of that frequency.

PULSE DISCHARGE TUBE: A gas triode used in the bootstrap driver for switching the pulse forming line to its terminating resistance.

PULSE RECURRENCE FREQUENCY (Abbr. PRF): Pulsing rate or repetition rate of the RF transmitter.

PULSE WIDTH: The elapsed time between the start and finish of a single pulse.

PYRAMID WAVE: A triangular wave, the sides of which are approximately equal in length.

QUIESCENT PERIOD: The resting period or the period between transmitted pulses.

RACON: A RAdar beaCON.

RADAR (RADIO DETECTION AND RANGING): Generic term applied to electrical equipment capable of performing the following functions: (1) Transmitting RF energy in the form of recurrent pulses, each pulse being of a short duration.

(2) Receiving a component of the transmitted pulse whenever this energy is reflected in such a manner as to return to the transmission point.

(3) Measuring the time interval between the transmission of a pulse and its return as reflected energy (the echo).

(4) Indicating the direction or bearing of the reflecting surface which caused the transmitted pulse to return as an echo.

The principle use to which RADAR is put is to obtain an indication of the presence, range, and bearing of unknown ships and aircraft. RADARS are also sometimes used for navigational purposes and as absolute altimeters.

RADAR CONTROL: The position from which the control of RADAR equipment is accomplished. This term applies specifically to the detection type RADAR. Fire control RADAR is controlled from the director with which it functions.

RADAR PLOT: Space provided in which to plot the positions of other vessels and/or airplanes by information obtained from RADAR equipment.

RANGE MARKERS: Sharp voltage pulses of accurately controlled frequency to indicate range when synchronized with and superimposed on the sweep.

R.D.F. (RADIO DIRECTION FINDING): British term for RADAR.

RECEIVER GATING: Applying operating voltages to one or more stages of intermediate frequency amplification in a receiver during that part of a cycle of operation when reception is desired.

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REFLEX KLYSTRON OSCILLATOR: (See KLYSTRON)

REPETITION RATE OSCILLATOR: Any type of oscillator which is used to determine the pulse recurrence frequency of a RADAR transmitter. Sometimes called TIMING OSCILLATOR.

REPLY RECEIVER: (See RESPONSOR)

REPROD (RECEIVER PROTECTION DEVICE): A part of the duplexer assembly used in RADAR equipment to prevent overloading of the receiver by the transmitted pulse. A REPROD together with a DECOUPLER makes a DUPLEXER.

RESONANT CAVITY: A form of resonant circuit in which the current is distributed on the inner surface of an inclosed chamber. By making the chamber of the proper dimensions the circuit can be made to have a high Q at microwave lengths. The resonant frequency of a cavity can be changed by adjustment of screws protruding into the cavity or by warping the cavity.

RESPONDOR: A receiver used specifically in any IFF system to receive the reply to an interrogation signal. (See REPLY RECEIVER)

RETRACE: The return of a trace or sweep described on the screen of a cathode ray oscilloscope to its starting point; the useless part of a total trace. In RADAR, the retrace is ordinarily blanked out by the use of suitable circuits, usually connected so as to drive the grid of the CRT to cutoff during this portion of the cycle. Also called FLYBACK.

RHUMBATRON: A resonator of the hollow cavity type, in which rythmic oscillations are made to occur.

RING OSCILLATOR: A type of oscillator used in some RADARS in which any even number of tubes are arranged in a ring. Between each pair of adjacent tubes is a tuned quarter wave line functioning as a balanced tank circuit. The open ends of each line are connected either to two grids or to two plates, alternating around the ring. Coupling between plate and grid circuits is chiefly through the internal capacity of the vacuum tubes. The balanced nature of each tank circuit puts equal RF voltages of opposite polarity on adjacent tubes. Therefore, diametrically opposite plates have identical polarities. Also called SERIES OSCILLATOR.

ROOSTER: A type of RADAR beacon.

ROUND TRIP ECHOES: Echoes which are returned from large targets in excess of maximum range and on a subsequent sweep appear to be at close ranges. These signals are differentiated from surface craft or aircraft targets at close ranges by differences in the character of the fading.

SALISBURY DARKBOX: An isolating chamber used for test work in connection with RADAR equipment. The walls of the chamber, or box, are especially constructed to absorb all impinging radiational energy at a certain microwavelength.

SAWTOOTH GENERATOR: A sweep generator producing a waveform resembling a sawtooth. (See SWEEP GENERATOR)

SCANNER: A type of spinner in which a parabolic antenna is made to oscillate back and forth from a center position. The oscillation may be on a horizontal or a vertical plane or on a combination of both.

SCANNING: Usually the action of the sweep circuit on the deflection elements of the Cathode Ray Tube in the Radar indicator. The action causes the spot on the tube screen formed by the electron beam to be

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deflected so that it moves back and forth or in a circle around the screen. Scanning may also, in some cases, refer to the action of Radar antennas of the spinner type.

SEA RETURN: In Radar, deflections of the sweep in the Radar Indicator caused by reflection of transmitted pulses from the sea.

SEARCH: The term applied to that phase of Radar operation when the lobe or beam of radiated energy is projected in such a manner as to cover a large area. This may be accomplished by a broad beam antenna, a rotating or scanning antenna.

SELF PULSING: A circuit arrangement of the RF oscillator such that a special type of GRID PULSING is obtained. Self pulsed oscillators utilize a special circuit which automatically stops and starts the oscillations at the pulsing rate. No auxiliary oscillators or mechanical circuits are required. (See also BLOCKING OSCILLATOR, GRID PULSING, PLATE PULSING)

SENDER: (1) The transmitting circuit in IFF transpondors. The receiver in the transpondor triggers the sender, or transmitter, on receipt of an interrogation signal, and the sender transmits a coded reply.

(2) A movable quartz crystal used in some RADAR equipment to produce a state of stress through piezo-electric action, and to communicate the state of stress through a liquid to another crystal by means of a wave-train of alternating compression and tension waves.

SERIES OSCILLATOR: See RING OSCILLATOR.

SILICA GEL: A chemical having moisture absorption properties, used in connection with the dehydration of transmission lines in RADAR equipment.

SLOTTED LINE: (Sometimes called Exploded Line) A device for determining the characteristics of transmission lines and antennas. See TRAVELING DETECTOR.

SPINNER: A spinner consists of a parabolic reflector, the mechanical assembly for supporting the reflector, and the gear and motor drives used to rotate the reflector. The rotation may be along a horizontal or vertical axis or a combination of both.

SPOT ERROR INDICATOR: See "G" INDICATOR

SQUEGGING CIRCUIT: See BLOCKING OSCILLATOR.

STEP: A sharp vertical drop produced in the sweep of the indicator pattern in certain RADAR equipments. Suitable electronic circuits controlled from the front of the indicator permit moving the step along the sweep trace until its position coincides with that of the desired echo signal. Mechanical indicating dials geared to the shaft of the control knobs give the distance to the target directly in yards when the step is moved to the position coinciding with that of the echo.

SWEEP DISCHARGE TUBE: See SWEEP GENERATOR.

SWEEP GENERATOR: The circuit of a RADAR indicator which applies voltages or currents to the cathode ray tube deflection elements in such a manner as to make the rate of deflection of the electron beam a known function of time, against which other periodically occurring electrical phenomena may be examined, compared or measured. Sometimes called SWEEP DISCHARGE TUBE, TIME BASE GENERATOR.

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SYNCHROSCOPE: An oscilloscope on which recurrent pulses or waveforms may be observed, which incorporates a sweep generator that produces one sweep for each pulse, regardless of frequency, thus allowing only one cycle to be viewed on the screen.

TR BOX: (Transmit-Receive) The duplexing circuit in microwave-length RADAR equipment. (See DUPLEXER)

TR CAVITY: (See TR BOX)

TICKET TUBE: Material used as a waveguide for low or medium power microwave RADAR equipment. The material is a hollow brass pipe, rectangular in cross section.

TIME BASE: The voltage generated by the SWEEP GENERATOR circuit in the RADAR indicator. The wave-shape of the voltage generated is such as to cause a trace to be described on the screen of the cathode ray tube which is either linear with respect to time, or if nonlinear, is still at a known timing rate.

TIME BASE GENERATOR: (See SWEEP GENERATOR)

TIMING OSCILLATOR: (See REPETITION OSCILLATOR)

TRACE: The visible line or lines which appear on the screen of the cathode ray tube in the RADAR indicator when a varying electric current or voltage is applied to the deflection elements of the tube. The lines appear because the varying electric or magnetic field between the deflection elements displace the electron beam shot from the electron gun within the tube. The beamed electrons thus displaced give motion to the fluorescent spot they cause by impinging on a crystalline substance at the end of the tube. If the deflection is accomplished at a rate (faster)than approximately 0.1 sec. (10 cps) the spot appears to form a continuous line or trace.

TRAIN: To aim or direct as the RADAR antenna, in a horizontal plane.

TRANSPONDOR: The unit of the IFF system which receives the interrogator signal and automatically transmits the reply.

TRAVELING DETECTOR:
(1) A probe mounted on a slider and free to move along a longitudinal slot cut in a waveguide or concentric transmission line. The traveling detector is connected to auxiliary measuring apparatus, and forms a means of examining the relative magnitude of any standing waves that may be present in the system. The whole system is known as a SLOTTED LINE.
(2) A portable detector for connecting to the output of an IF amplifier. The input to the amplifier is a frequency modulated signal, which after being demodulated is taken from the detector and applied to a scope to describe the selectivity curve of the amplifier.

TRIDENTS: A waveguide distribution system for the vertical rows of polystyrene radiators on the Model FH (Mark 8) RADAR equipment (See POLYROD ANTENNA)

TRIGGER: To set or to cause to start (or stop) suddenly. Usually applied to vacuum tube circuits. For example, to trigger a tube means to apply a voltage to the input or output circuit such that the tube, if non-conducting will suddenly begin conducting, or, if conducting, will suddenly cease.

TRIGGER CIRCUITS: Amplifiers in which the direct output voltage or current changes abruptly from one stable value to another stable value at a critical input voltage or current, and then changes back abruptly to approximately its original value at a different input voltage or current.

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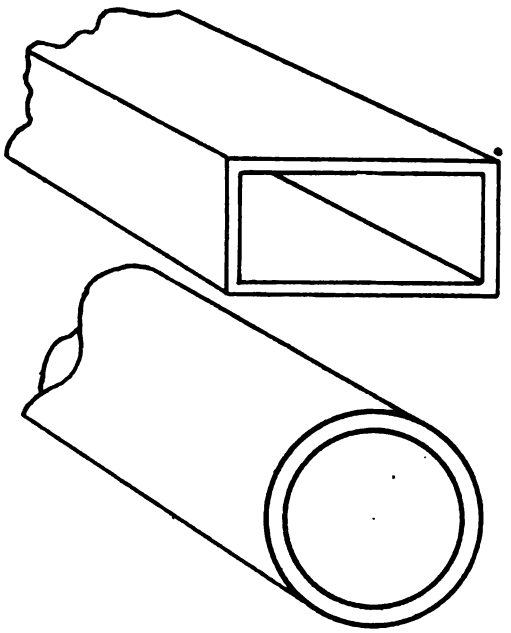
VIDEO AMPLIFIER: (See PULSE AMPLIFIER)

VOLTAGE REGULATOR: A circuit for removing low frequency and/or high frequency variation from a power supply.

WAVEGUIDE: Generic term used for transmission lines having no inner conductor; used to conduct microwave energy from the output of the transmitter to the antenna with minimum attenuation. In certain cases, no antenna is used with the waveguide, the wave being launched from the open end of the guide into the outside medium. In this event, the open end of the guide should be so constructed so as to form a fair impedance match with the outside medium. (See HORN)



Rectangular and Circular Waveguides

WINDSHIELD: In RADAR, a streamlined cover placed in front of airborne paraboloid antennas so as to minimize wind resistance. The cover material is such as to prevent appreciable attenuation to the radiation of RADAR energy.

WINGS: (See "G" INDICATOR)

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APPENDIX B

Fundamental Circuit Nomenclature

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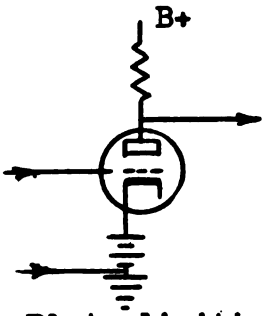
FUNDAMENTAL CIRCUIT NOMENCLATURE

1. LIMITER:

A circuit which limits or clips either or both the positive or negative portion of a waveform at a predetermined level.



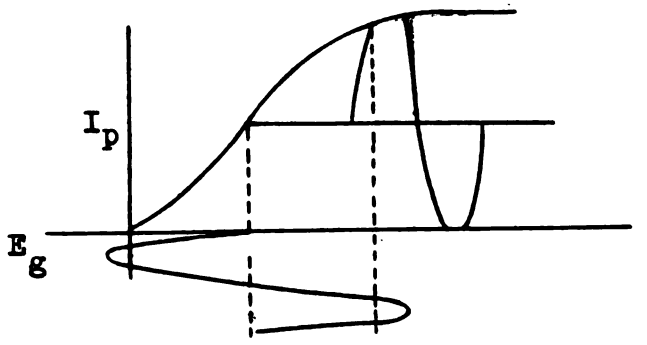
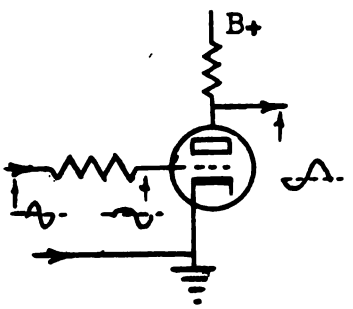
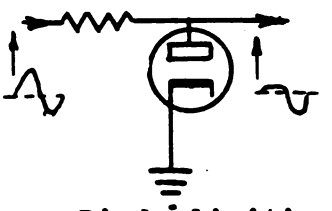


Plate limiting by overdriving a tube



Grid limiting is sometimes referred to as grid stopping

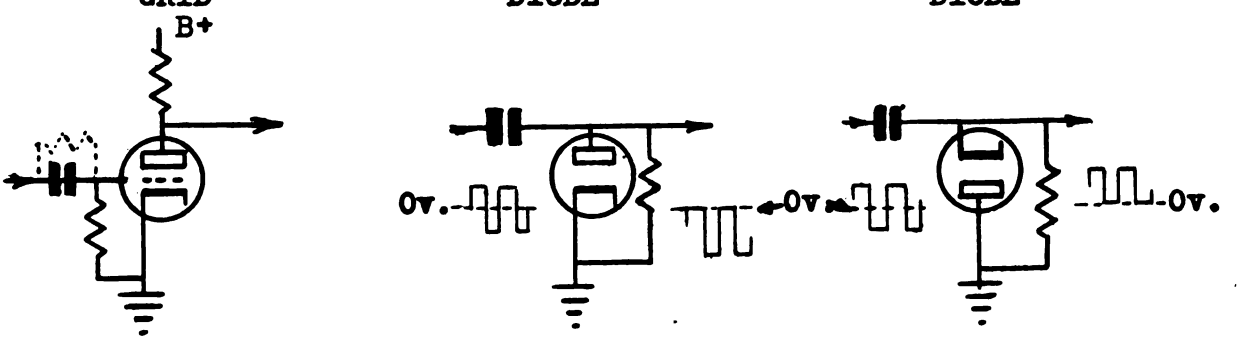


Diode limiting, similar in principle to grid limiting.

2. CLAMPING:

A circuit which clamps a waveform at either amplitude extreme to a given reference level of potential.

GRID DIODE DIODE



Figures 5, 6, and 7 are characterized by a short RC path for changes in charge on the condenser in one direction and a long RC path in the other direction.

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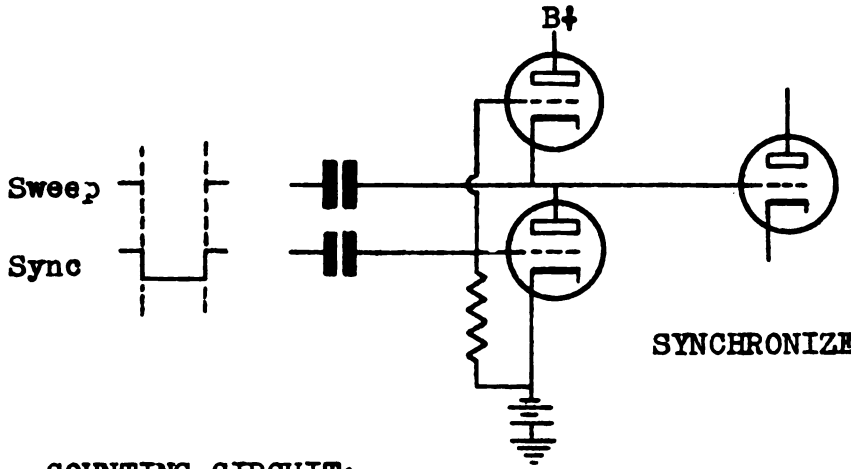
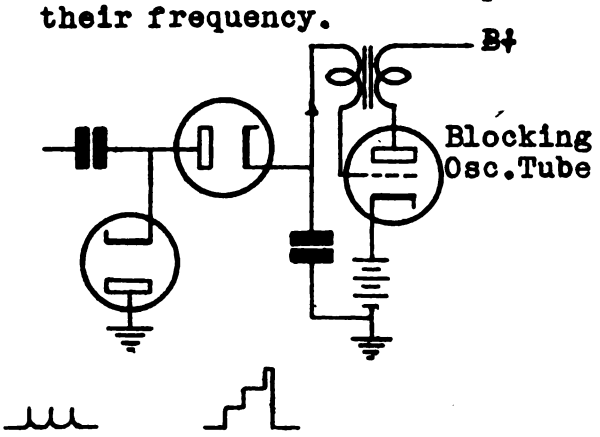
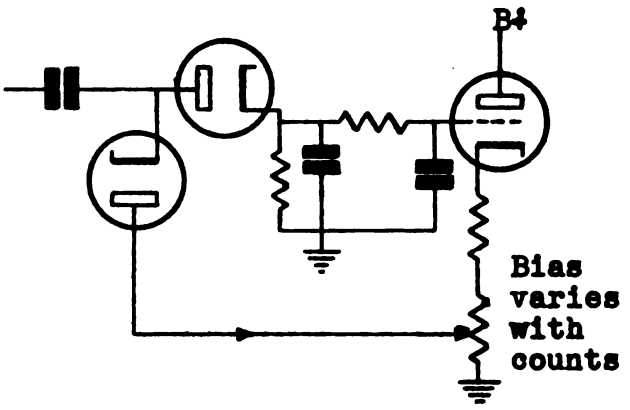


SYNCHRONIZED CLAMPING

3. COUNTING CIRCUIT:

A circuit which receives uniform pulses representing units to be counted and produces a voltage in proportion to their frequency.

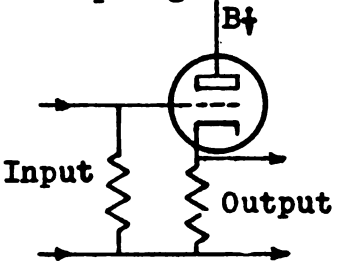




STEP BY STEP COUNTER

4. CATHODE FOLLOWER:

A degenerative vacuum tube circuit in which degeneration is produced by an unbypassed cathode resistor, the output being taken across this resistor. This circuit is essentially an impedance matching device with less than unity voltage gain but possessing power gain. The high input impedance and very low output impedance render it particularly suitable for coupling between pulse generative or pulse transmitting stages and transmission lines or circuits whose shunt capacity might otherwise cause objectionable effects. The output of a cathode follower is of the same polarity, and therefore "follows" the input grid voltage.



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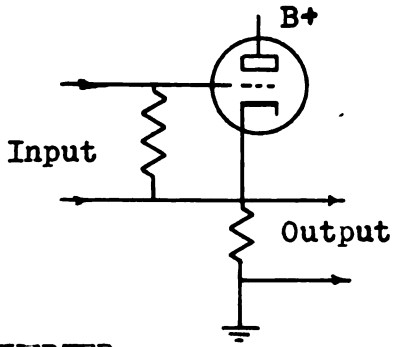
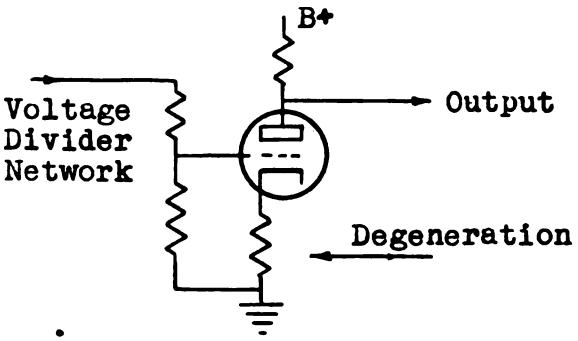
5. CATHODE COUPLED AMPLIFIER:

An amplifier with its load impedance in the low potential (to ground) part of the circuit rather than in the plate or high potential circuit. It amplifies the input wave without inverting its polarity.



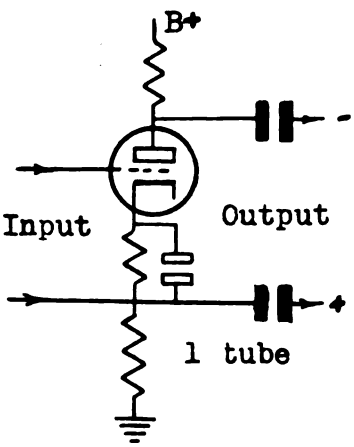
6. PHASE INVERTER:

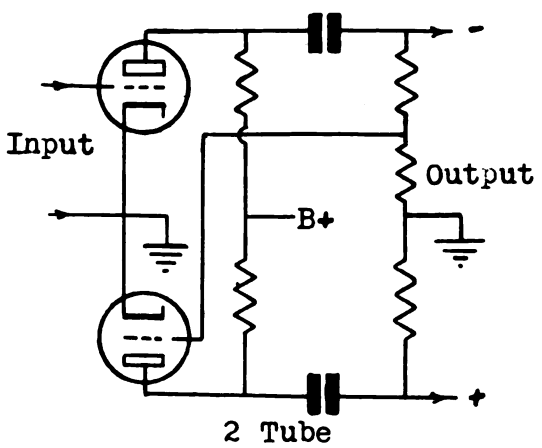
An amplifier employing degeneration and in some instances a voltage divider network in its grid circuit to invert the phase of a signal (without changing its amplitude).



7. PARAPHASE AMPLIFIER:

An amplifier used to convert a single input to a push-pull output.





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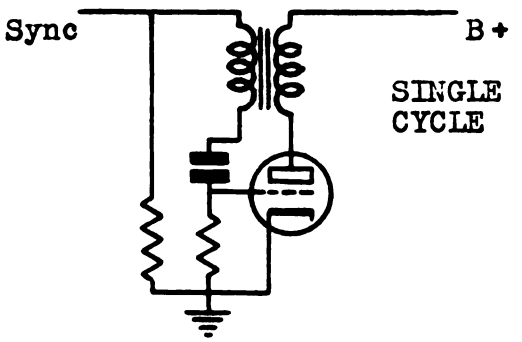
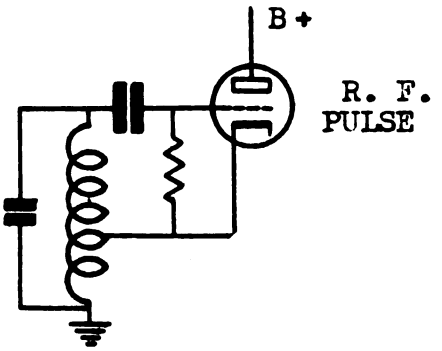
8. BLOCKING OSCILLATOR

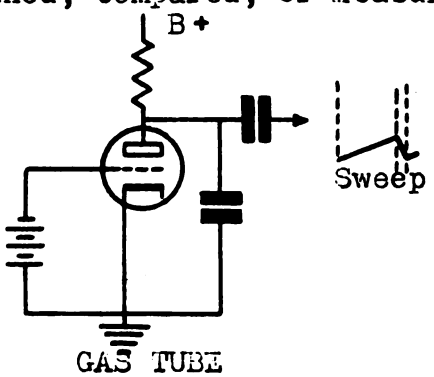
Any oscillator, running freely or controlled by a synchronizing voltage, which cuts itself off after one or more cycles by the flow of grid current charging a grid capacitor.

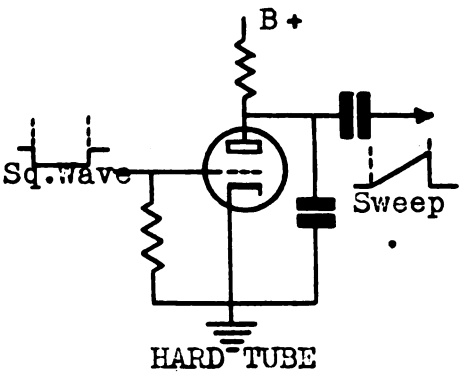




9. SWEEP GENERATOR:

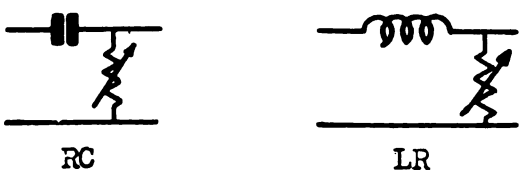
The circuit in the Radar indicator which applies voltages or currents to the cathode ray tube deflection elements in such a manner as to make the rate of deflection of the electron beam a known function of time, against which other periodically occurring electrical phenomena may be examined, compared, or measured.



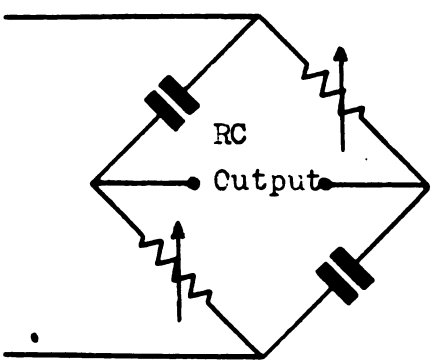


10. PHASE SHIFTING NETWORKS:

Any combination of inductance, resistance or capacity which is used to produce an out of phase voltage with respect to a reference sine voltage.



Maximum shift approaches 90°



Maximum shift approaches 180°

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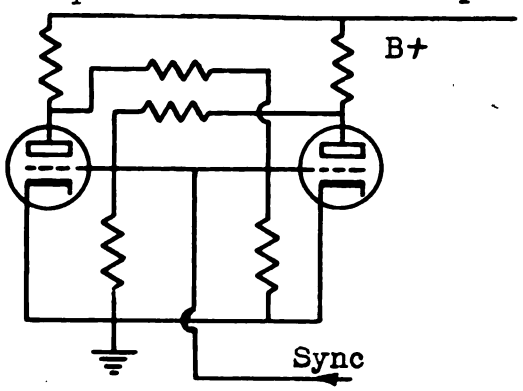
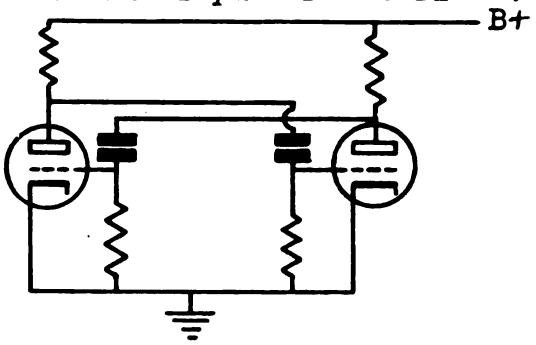
11. MULTIVIBRATORS:

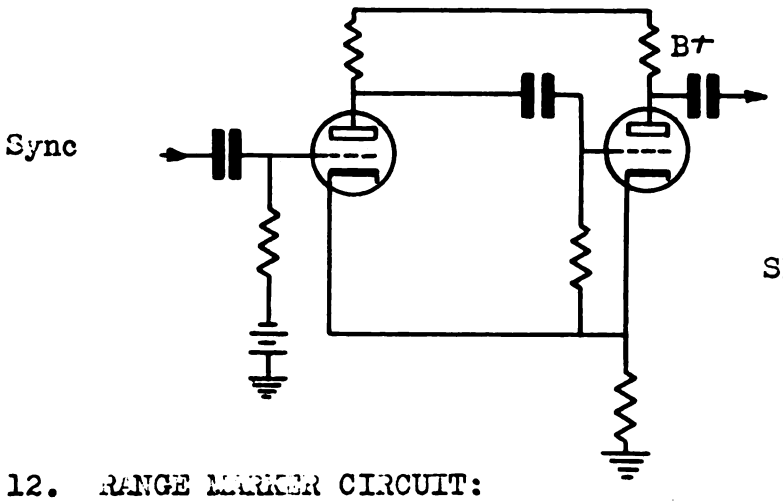
A form of relaxation oscillator consisting of two resistance or resistance-capacitance coupled amplifiers with the output of the second coupled back to the input of the first.



FLIP-FLOP



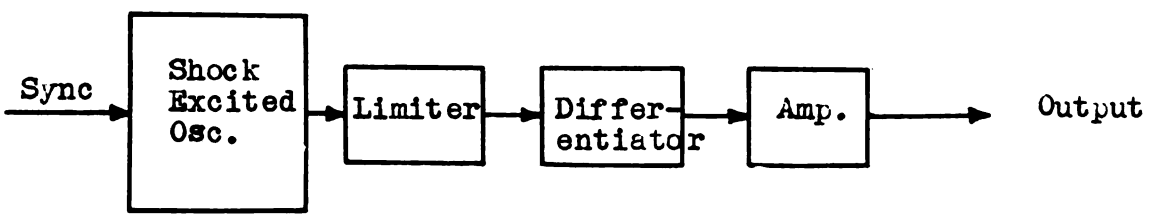
SQUARE WAVE MV:



SINGLE KICK

12. RANGE MARKER CIRCUIT:

Any circuit, external or internal to an indicator, which supplies sharp voltage pulses of accurately controlled frequency to indicate range when synchronized with and superimposed on the sweep.



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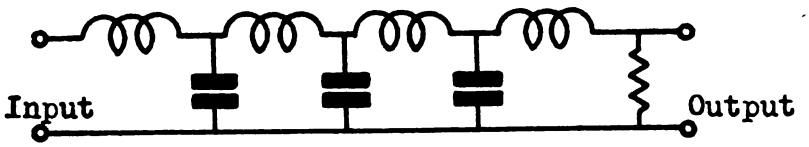
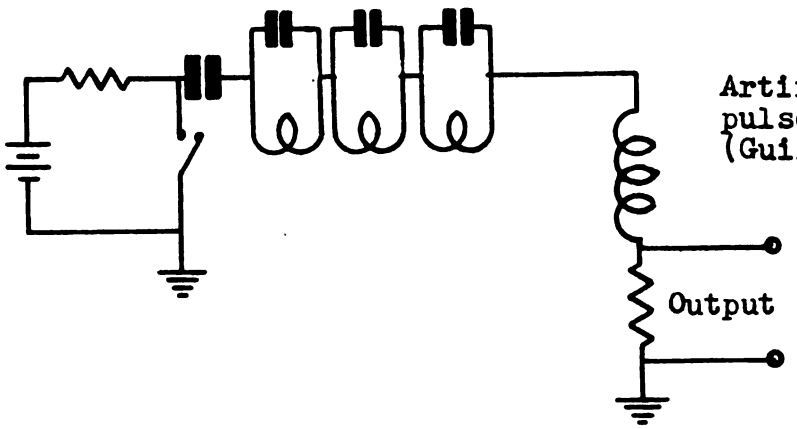
13. ARTIFICIAL LINES:

Any network composed of lumped constants which can be used to introduce a time-delay or to form an accurately timed pulse, similar to an ordinary transmission line with its own inductance and distributed capacity.



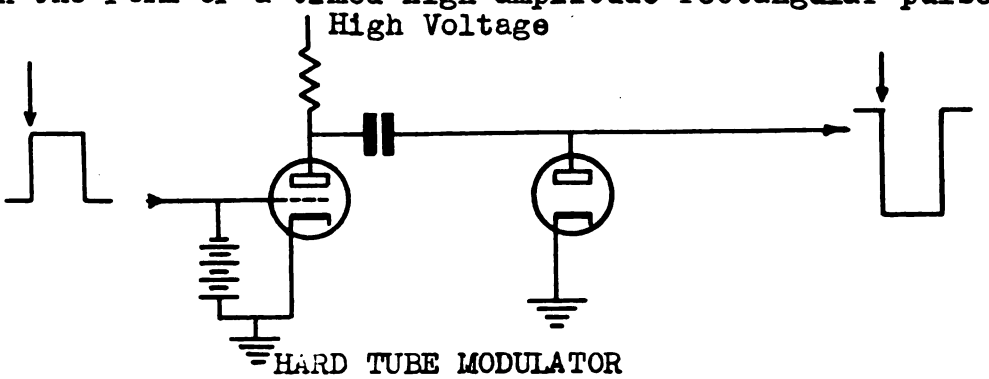
Artificial line as delay line



Artificial line as pulse forming line (Guillemin type)

14. MODULATOR:

Any circuit for supplying power to the RF oscillator in the form of a timed high amplitude rectangular pulse.



HARD TUBE MODULATOR

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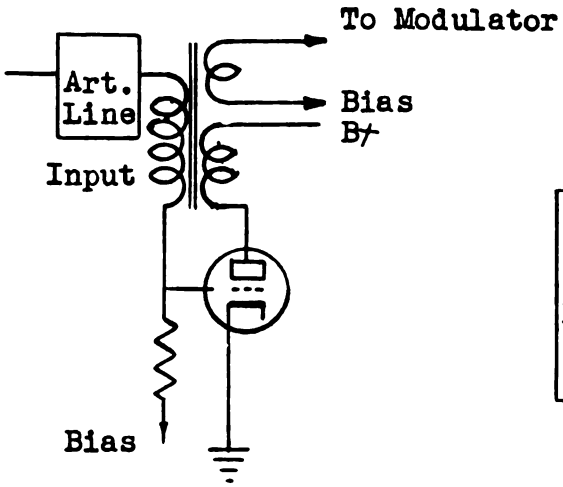
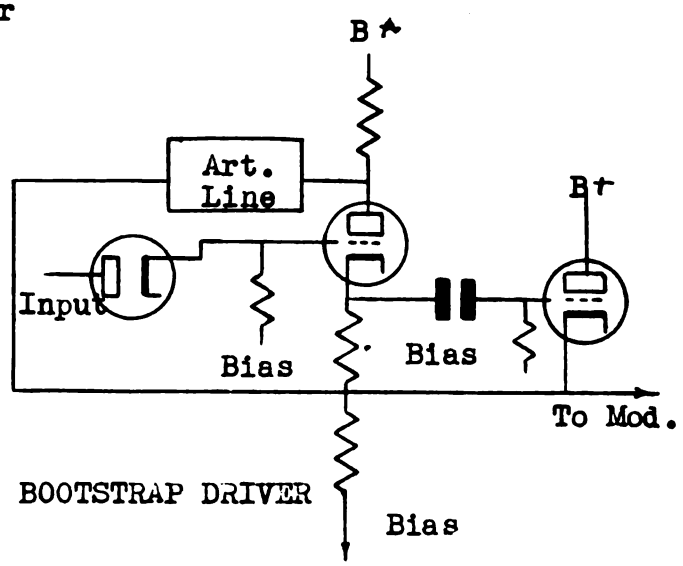
15. DRIVER:

A circuit which, when triggered, is designed to drive a modulator with a rectangular pulse of accurately timed width.



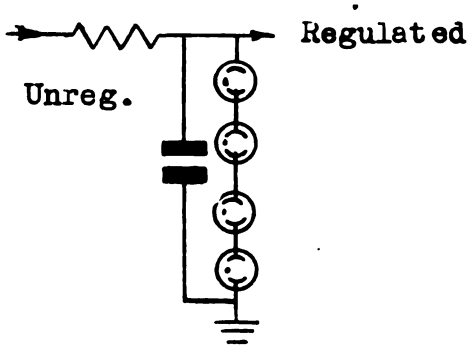
SINGLE TUBE DRIVER



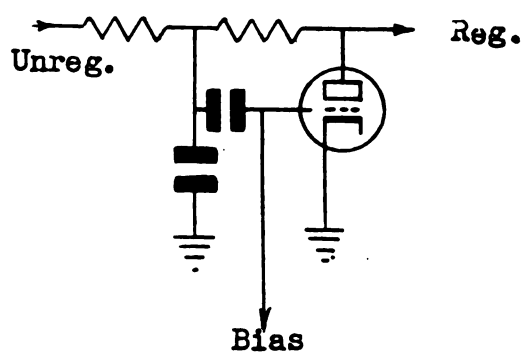
BOOTSTRAP DRIVER

16. VOLTAGE REGULATOR:

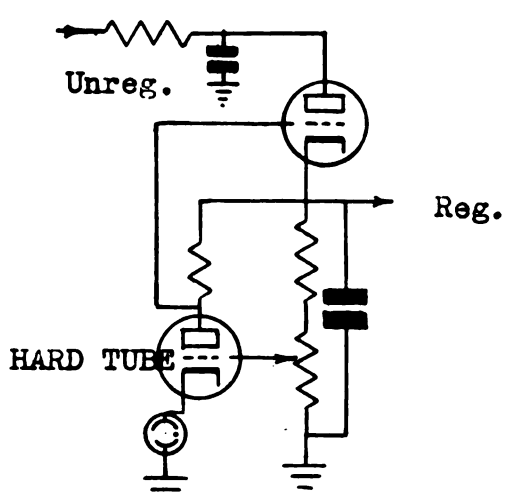
Any circuit for removing low frequency and/or high frequency variations from a voltage supply.



GAS TUBE



HARD TUBE



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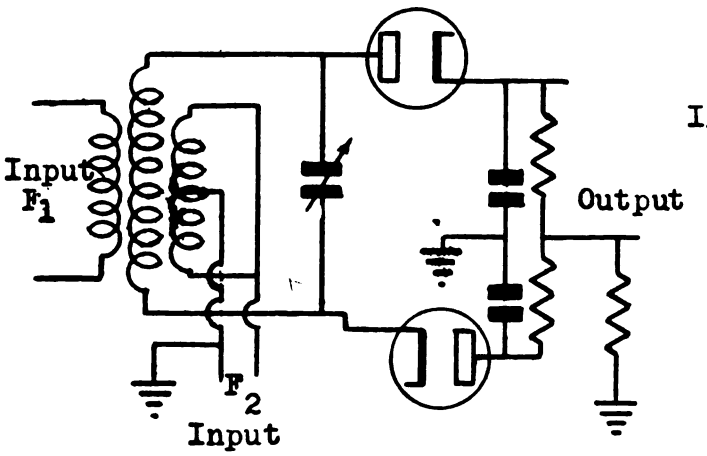
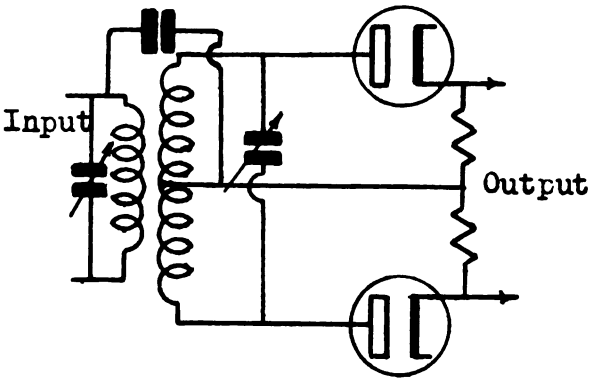
17. BALANCED DETECTOR:

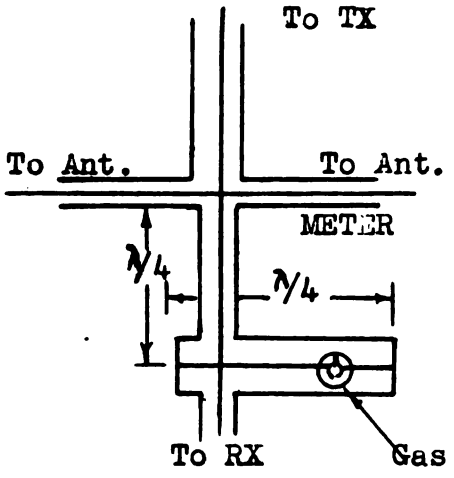
A circuit useful for detecting changes in frequency or phase rather than changes in amplitude. The difference in tube load current is the useful feature of the circuit. The load current flowing in each tube is in proportion to the magnitude of the resultant voltage on that tube. Fig. 35 is designed to detect the beat produced by mixing two varying frequencies at the input. Fig. 36 is commonly preceded by a limiter stage to remove any amplitude modulated component and when so operated is usually called a discriminator particularly for automatic frequency control circuits.

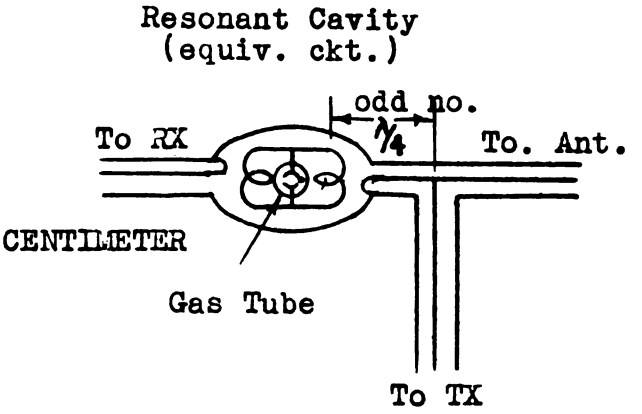




18. DUPLEXER:

The protective arrangement used in any Radar unit to protect the receiver from the transmitted energy when using a common antenna, and allow all of return signal to enter receiver.





19. MICROWAVE LOCAL OSCILLATORS:

Any of several types of reflex klystrons or lighthouse tubes used as RF to IF conversion oscillators.

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20. MICROWAVE MIXERS:

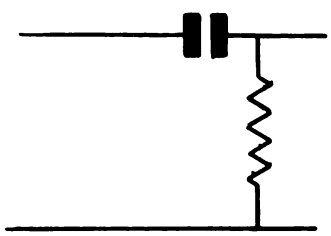
Any circuit for mixing the microwave oscillator signal with the return signal, including grounded grid triodes and crystal mixers.

21. CONTROL SYSTEM:

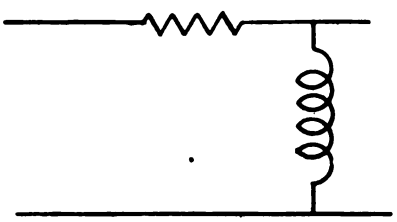
Radar control systems may consist of arrangements of selsyns, selsyns and amplidynes, or potentiometers employed to synchronize the movements of a given mechanical system with other mechanical systems or with cathode ray tube deflection systems.

22. DIFFERENTIATOR CIRCUIT:

One which produces an output voltage substantially in proportion to the rate of change of the input voltage or current.



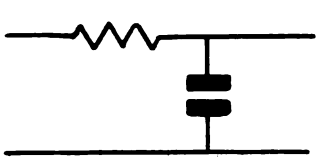
RC



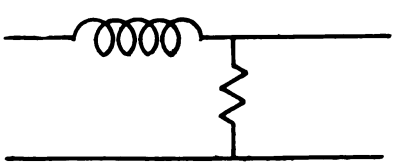
L/R

23. INTEGRATOR CIRCUIT:

One which sums up, or produces an output voltage substantially in proportion to the frequency and amplitude of the input pulses.



RC



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APPENDIX C

Table of Circuit Applications

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EQUIPMENT	POWER	TRANSMITTER			ANTENNA SYSTEM			TIMING	RECEIVER			INDICATOR				
		DRIVER	MODULATOR	R. F. OSC.	LINE	DUPLEXER	RADIATOR	OSCILLATOR	TYPE	MIXER	LOCAL OSC.	SCOPE	SWEEP	GATING	RANGE MARKS	RANGE
ASA	28 v. DC to 115v/800cps inverter	Two tube trigger pulse amp.	Hard tube	Push-pull, tuned plate-tuned fil.	Flexible coax.	Gas tube	Stacked Yagi steerable	82 KC Xtal oscillator	Superhet.	Beam deflection	Triode	L-scan J-scan	Electromag. Electrostat.		Xtal osc & two freq. dividers	Radar: 20, 73 miles. Alt: 2000, 20000 ft.
ASB	115v/800cps			Tuned plate-tuned fil. (blocking)	Flexible coax.	Polyplex. (gas tube)	Yagi steerable	Timing pulse from R. F. osc.	Double superhet.	Triode and pentode grid mixing	Triodes, (Hartley and Colpitts)	L-scan	Electrostat.	Differentiated sweep on grid	External test set, shock osc.	7, 28, and 70 miles
ASC	28 v. DC to 115v/400cps inverter	Bootstrap	Hard tube	Microwave type	Rigid coax.	T-R box	Dipole with parabolic reflector	800 cps MV (synchronized)	Superhet.	Grounded grid triode	McNally osc (reflex klystron)	P-scan A-scan B-scan (aux.)	Electromag. Electrostat. Electromag.	On cathode on grid on grid	Range mark MV	5, 20, 50, and 100 miles
ASD	120v/800cps	Single tube	Hard tube	Microwave type	Wave quide	T-R box & anti T-R box	Flared wave guide with directors & parabolic reflector	Blocking oscillator	Superhet.	Crystal	Sheperd osc (reflex klystron)	2 B-scan	Electromag.	On cathode	Shock osc. with sustaining MV	4, 40, and 100 miles
ASE	80v/800cps			Tuned plate-tuned grid (blocking)	Flexible coax. & two conductor cable	Polyplex. (gas tube)	Yagi and colinear	Timing pulse from R. F. osc.	Superhet.	Pentode connected as diode	Triode (Hartley)	L-scan	Electrostat.	Differentiated sweep on grid	External test set, shock osc.	9, 36, and 90 miles
ASG	120v/800cps	Single tube	Hard tube	Microwave type	Rigid coax.	T-R box	Dipole with parasitic & parabolic reflector	800 cps MV	Superhet.	Crystal	Reflex klystron	2 P-scan A-scan	Electromag. Electrostat.	On cathode on grid	Shock osc.	5, 20, 50, and 90 miles
AYA	14 v. DC inverter & dynamotor	One tube trigger pulse amp.	Hard tube	Push-pull, tuned plate-tuned grid	Flexible coax.		Two dipoles	24.6 KC and 82 KC osc.	Double superhet.	Pentode grid mixing	Triodes (Colpitts and Hartley)	J-scan	Electrostat.			2000 and 20000 ft.
AYB (AYD)	28 v. DC dynamotor	120 cps oscillator	Magnetic frequency modulator	Push-pull, tuned plate-tuned fil.	Flexible coax.		Dipole	120 cps osc. (used as driver)	Balanced detector (freq. mod)			Meter and lights				400 feet
ABD (AYC)	Dynamotor		Received pulse amplifier	Push-pull, tuned plate-tuned grid and Hartley	Untuned open		Balanced "V" (aperiodic)	Triggered by received pulse	Super-regenerative							
ABK	Dynamotor		Received pulse amplifier	Triode with variable inductance	Flexible coax.		Quarter wave stub	Triggered by received pulse	Super-regenerative							

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APPENDIX D

Introduction to Representative Types of Airborne Equipment

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FUNCTIONAL BLOCK DIAGRAM

ASB RADAR

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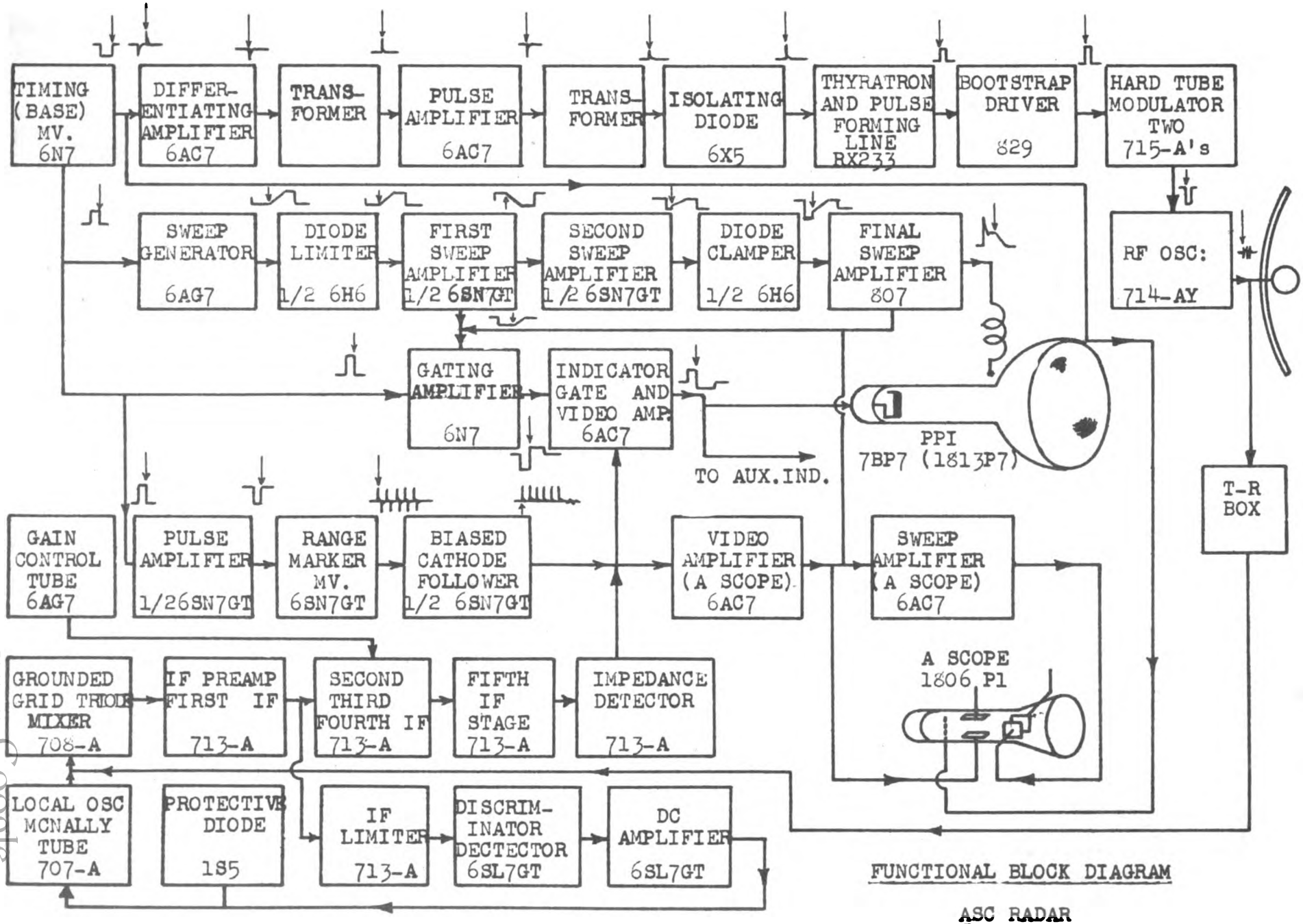

FUNCTIONAL BLOCK DIAGRAM

ASC RADAR

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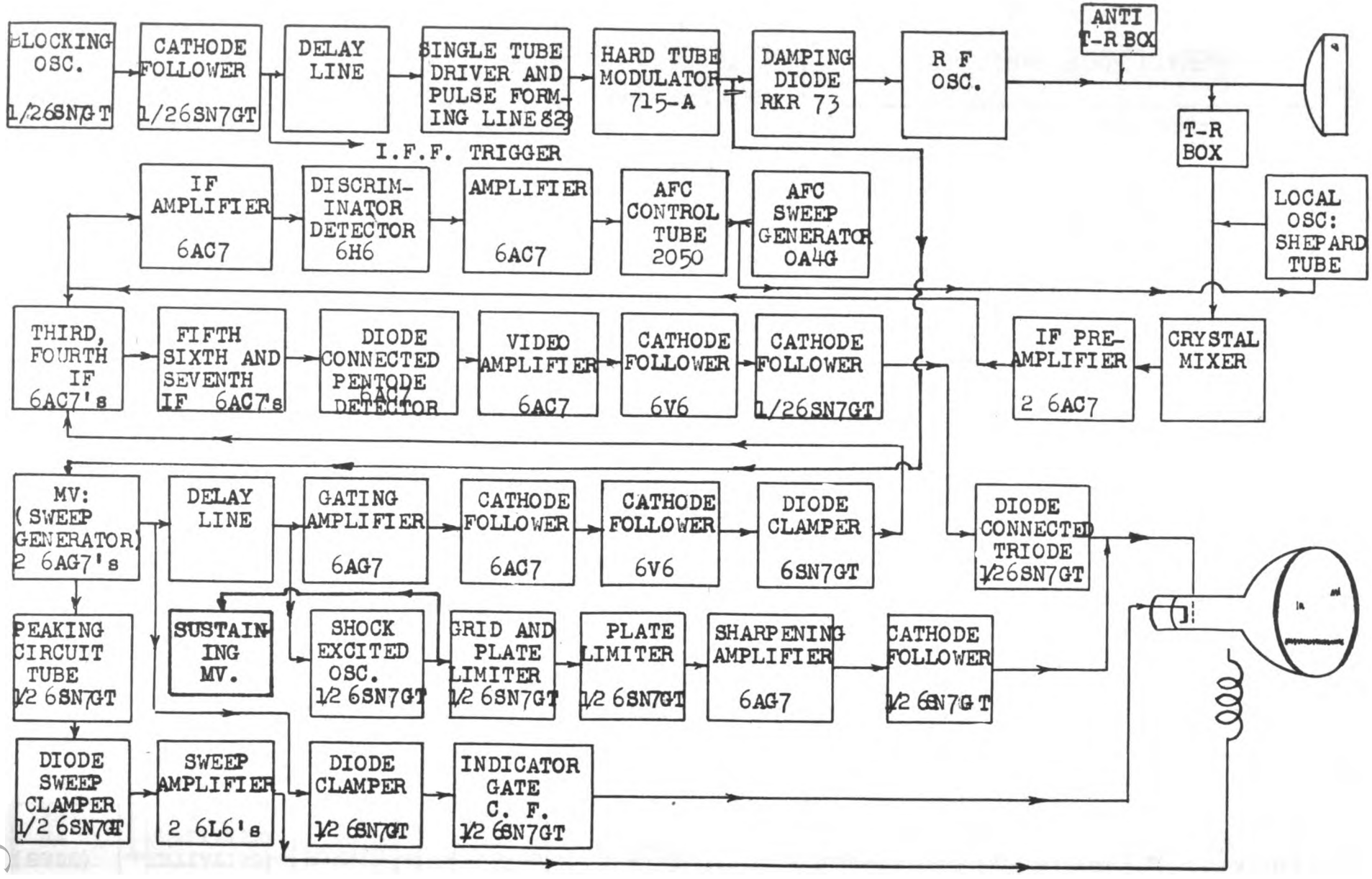

FUNCTIONAL BLOCK DIAGRAM
ASD RADAR

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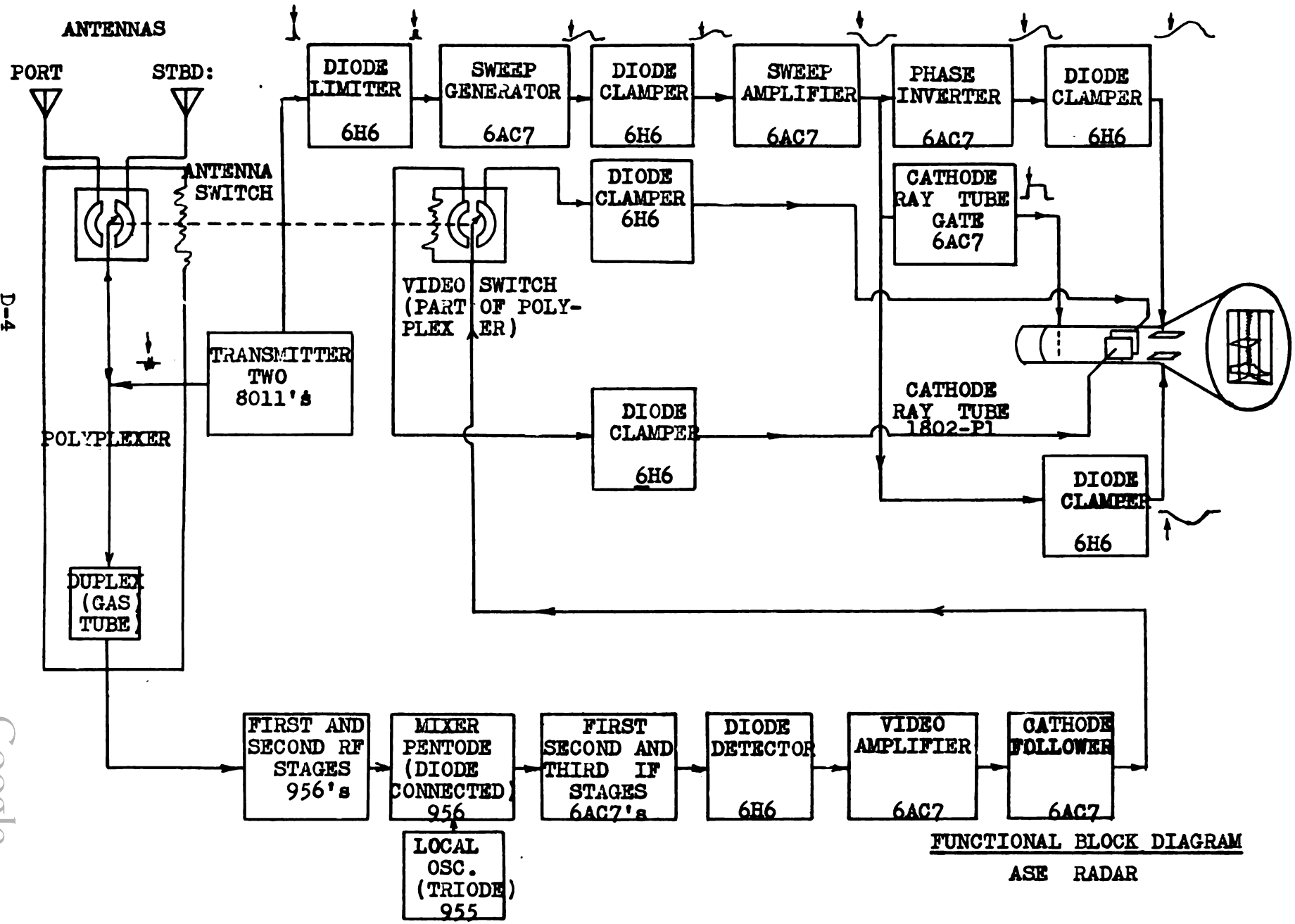

FUNCTIONAL BLOCK DIAGRAM

ASE RADAR

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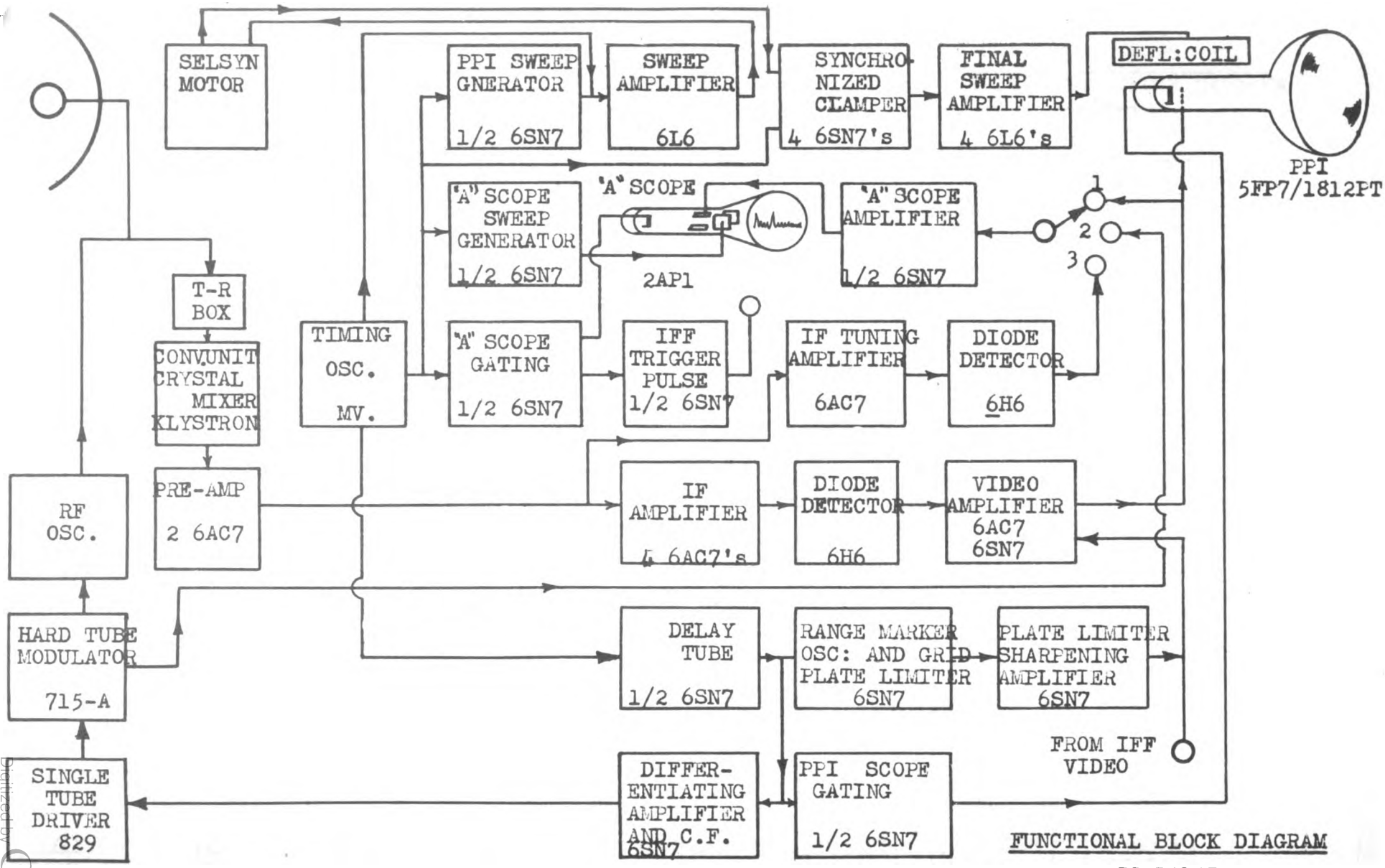

FUNCTIONAL BLOCK DIAGRAM

ASG RADAR

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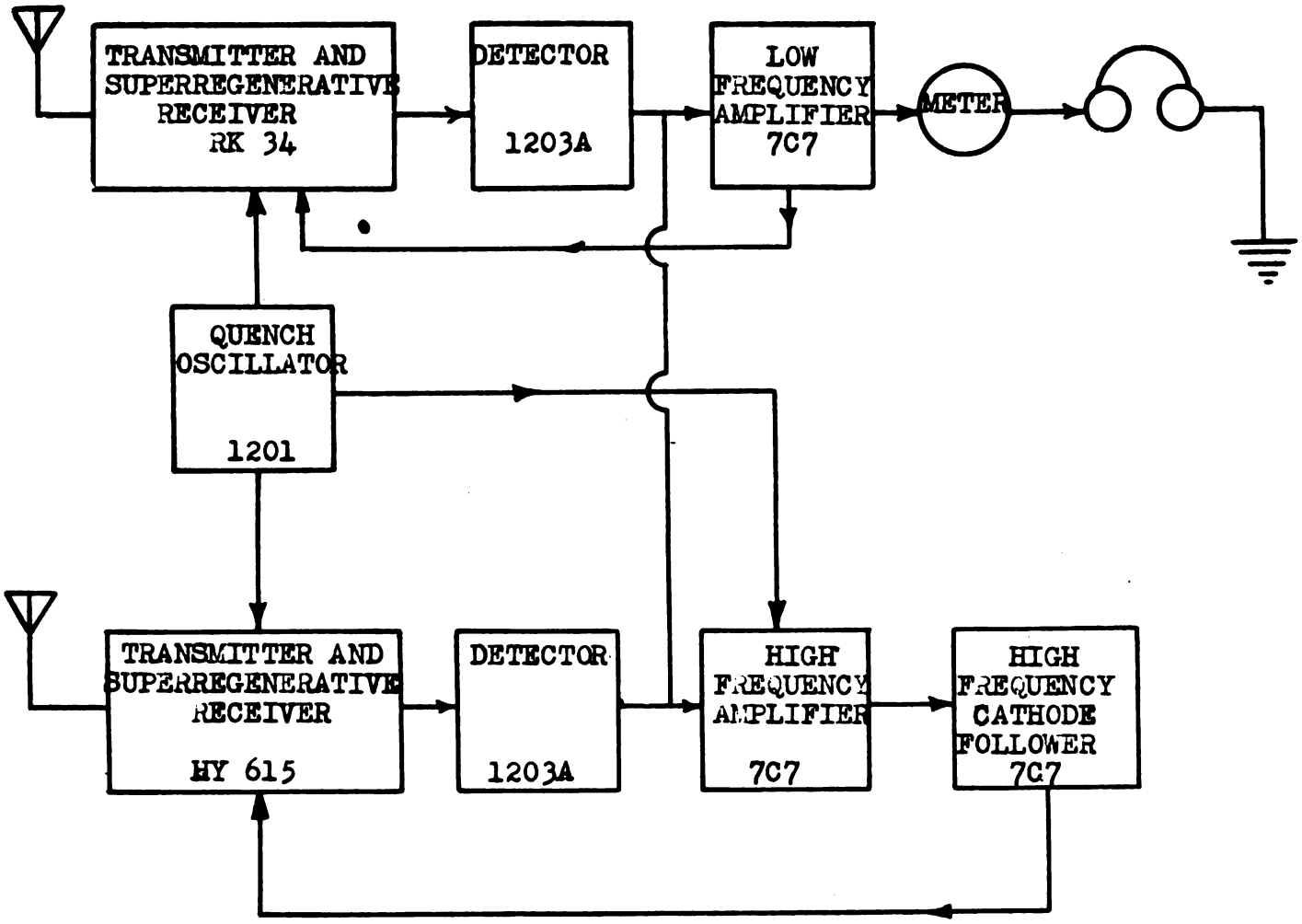

FUNCTIONAL BLOCK DIAGRAM

ABE RECOGNITION

EQUIPMENT

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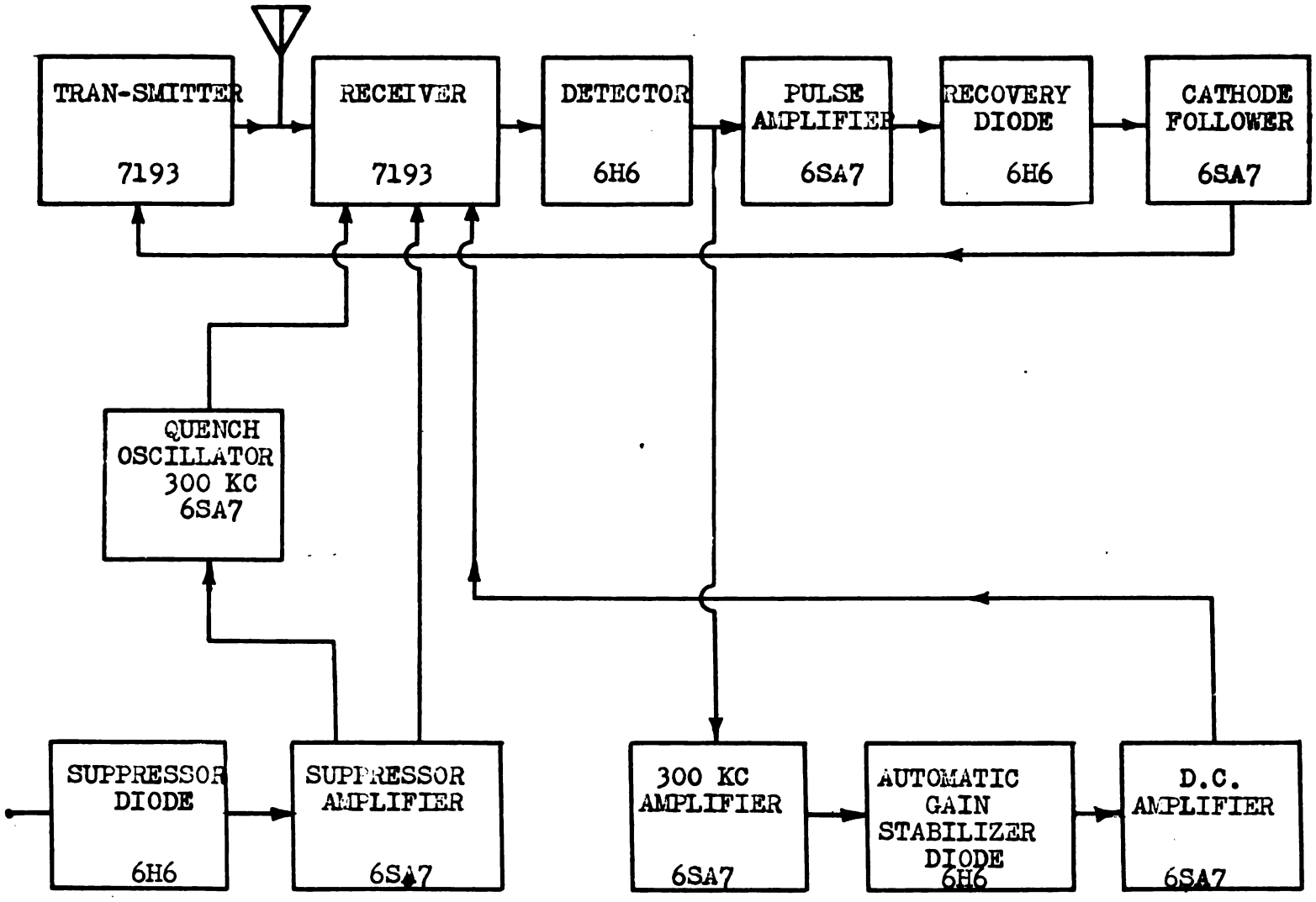

FUNCTIONAL BLOCK DIAGRAM

ABK RECOGNITION

EQUIPMENT

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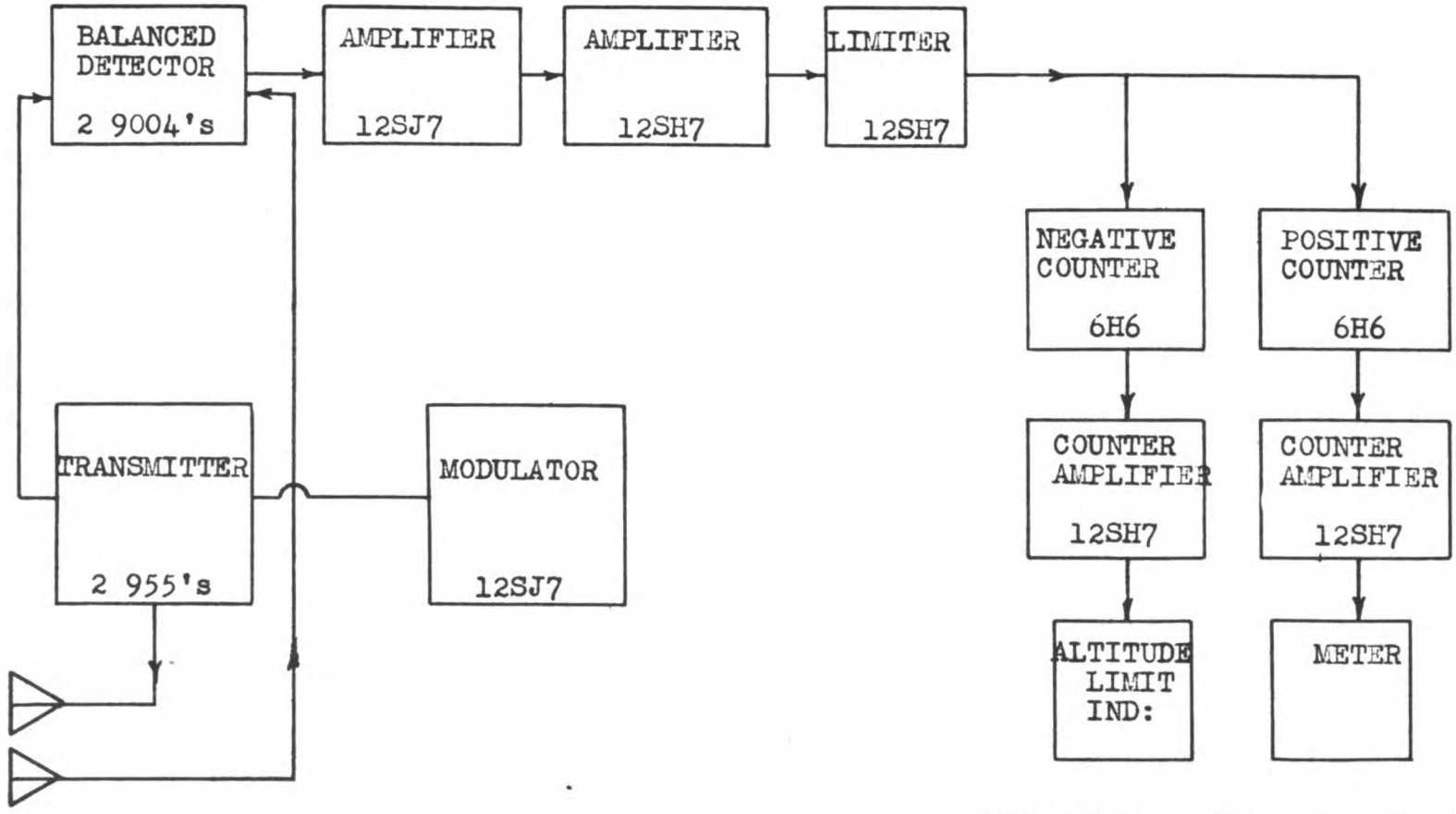

FUNCTIONAL BLOCK DIAGRAM

AYB ABSOLUTE ALTIMETER

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APPENDIX E

AN Nomenclature

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AN NOMENCLATURE

(NAVY USED EQUIPMENT)

Radar (Assemblies - APA)

AN Designation	Former Navy Designation	Former Army Designation	Description
*AN/APA-1			Airborne Radar Repeater Indicator Equipment - used with ASB or SCR-729.
AN/APA-2(XA-)			"S" Band Antenna Equipment - used with SCR-717 and ASV.
AN/APA-3(XA-)			"X" Band Antenna Equipment - used with ASV and SCR-717.
AN/APA-4(XA-)			Airborne Audible Warning Radar Attachment - used with SCR-517, SCR-717 or any "S" or "X" Band Radar System.

Radar (Gun Directing - APG)

AN/APG-1	AGL-1 (W.E.)	SCR-702B	"S" Band Airborne Aircraft Detector and Gun-Aiming Device.
AN/APG-2	AGL-1 (GE)	SCR-702A	"S" Band, Airborne Detector and Gun-Aiming Device.
AN/APG-3(XA-)	AGLX		"X" Band, Airborne Radar Gun Directing Equipment - similar to AN/APG-1 and AN/APG-2.
AN/APG-4	RL-101 (Sniffer)		UHF, FM, Airborne Radar Low Altitude Bomb Release, automatic.
AN/APG-4X			Same as An/APG-4 except operate on 14 volt D.C.
AN/APG-5	ARO	SCR-726	Airborne Gun Ranging Equipment.

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Radar Navigational Aids - APN)

AN Designation	Former Navy Designation	Former Army Designation	Description
*AN/APN-1	AYF		Airborne Radar Altimeter. Same as *AN/APN-1 except substitute *1D-1/ARN-1 for *1D-14/APN-1. (different indicator.)
*AN/APN-1B			Same as *AN/APN-1 except does not include *1D-14/APN-1. (indicator).
*AN/ARN-1	AYD-1.-4.-5		Airborne Radar Altimeter.
*AN/APN-4		SCR-622	Loran.
AN/APN-7	ABM (Exp. equip. CXCG)		Airborne Transponder Beacon.
AN/APN-8	CXCG-2		Airborne Transpondor Beacon (26volt D.C. supply).
AN/APN-8X	CXCG-1		Same as AN/APN-8 except operate from 13 volt D.C. Supply.
AN/APN-8Y	CXCG		Same as AN/APN-8 except operate from 80 to 115 volt 400 - 3400 cycle AC supply

Radar (Special - APQ)

AN/APQ-1			Special Radio Equipment (RCM).
AN/APQ-2	F1500-R.R.L.	Similar to: RC-156 except for freq. change.	
AN/APQ-3	ARQ	A-2600 R.R.L.	Airborne Radio Search Receiver (RCM).
AN/APQ-4	ARR	A-2700 R.R.L.	Airborne Radio Search Receiver (RCM).
AN/APQ-5		RC-217 - used with SCR-517C	Auxiliary Electronic Bombsight Equipment

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AN Designation	Former Navy Designation	Former Army Designation	Description
Radar (Special - APQ)			
AN/APQ-5A			Similar to AN/APQ-5 except control box and tracking unit combined in one unit.
AN/APQ-8(XA-)			Airborne Electronic Equipment (RCM).
AN/APQ-9(XA-)	F903-R.R.L.	Similar to RC-156	Special Radio Equipment (RCM).
AN/APQ-13 (XA)		H2X Radiation Lab.	"X" Band, Airborne Radar Bombing Equipment.
Radar (Receiving APR)			
AN/APR-1	ARC-2		Airborne Radio Search Receiver (RCM).
AN/APR-1X			Same as AN/APR-1 except operates on 60 c/s instead of 400 to 2400 c/s power supply.
Radar (Search - APS)			
AN/APS-1 (XA-)			Radar Airborne Search Equipment - To operate with IFF, LAB and ground beacon. Multiple form factors with common components.
AN/APS-2	ASG-3	Similar to: SCR-617 SCR-517	"S" Band, Airborne Electronic Search Equipment.
AN/APS-2A	ASG-2		Same as AN/APS-2 except Spinner adapted for K Ship Installation.
AN/APS-2B	ASG-2		Same as AN/APS-2 except Spinner adapted for B-24 Installation.
AN/APS-3	ASD-1		"X" Band Airborne Search Radar.

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Designation	Former Navy Designation	Former Army Designation	Description
Radar (Search - APS)			
AN/APS-4	ASH		"X" Band Airborne Electronic Search - Intercept Equipment.
AN/APS-6	AIA-1		"X" Band, Airborne Search, Interception and Gun-Aiming Radar with Beacon Facilities.
AN/APS-8(8A-)			Tail Warning Equipment for use in fighter planes.
AN/APS-10 (XA-)			"S" Band, Lightweight Airborne Radar Search Equipment. Operate beacon and IFF equipment.
AN/APS-11 (XN-1)	AMC		Airborne Tail Warning Radar Equipment. UHF and FM.
AN/APS-13			"L" Band Airborne Tail Warning Equipment.
AN/APS-14			Airborne Radar Search Equipment.
AN/APS-15	H_2X		"X" Band, Airborne Electronic Search Equipment.
AN/APS-16	Similar ASB		"L" Band, Airborne Tail Warning Equipment.
AN/APS-17	ASJ		"S" Band, Airborne Tail Warning Equipment.
Training Equipment			
AN/APS-2-T1			Equipment for training personnel to read and interpret the Plan Repeater Indicator ID-2/APS-2.
AN/APQ-5-T1			Training Equipment to be used with AN/APQ-5.

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AN Designation	Former Navy Designation	Former Army Designation	Description
		Radar - (Transmitting - APT)	
AN/APT-1		RC-230	Special Radio Equipment (RCM).
		Radar (IFF - APX)	
AN/APX-1	ABF-2		Transpondor Equipment - similar to SCR-695.
AN/APX-1X			Same as AN/APX-1 except uses 14 volt D.C. Supply.
AN/APX-2	ABJ		An Airborne Interrogator - Responsor - Transpondor equipment.
		Radio (Communications - ARC)	
AN/ARC-1(XN-)	W.E. 233X		Airborne VHF Radio Communication Equipment.
AN/ARC-2(XN-2)			Airborne Radio Transmitting and Receiving equipment.
AN/ARC-4	W.E. 233A		Airborne VHF Radio Communication Equipment (24 volt supply)
AN/ARC-4X			Same as AN/ARC-4 except it uses only 12 and 24 volt supply.
AN/ARC-5			MF and HF Radio Equipment (Plate and Screen Modulated - ATA and Modified ARA also modified SCR-274N-VHF).
		Radio Navagational Aids - ARN	
AN/ARN-6		SCR-599	Airborne Automatic Radio Compass.
AN/ARN-7		SCR-639	Airborne Automatic Radio Compass.
AN/ARN-8	MBA		Airborne Radio Marker Beacone Receiving Equipment.

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AN Designation	Former Navy Designation	Former Army Designation	Description
Radio Navagational Aids - ARN)			
AN/ARN-9	ZA-2		Airborne Radio Instrument Approach Equipment.
Radio (Receiving - ARR)			
*AN/ARR-1	ZB-2 ZB-3		Homing Adapter used with Communication Receiver.
*AN/ARR-2	ZBX		Airborne Radio Homing Equipment.
AN/ARR-2X			Same as *AN/ARR-2 except operates on 12 volts instead of 24 volts D.C. supply.
AN/ARR-3		RC-222	Airborne RadioReceiver - used with AN/CRT-1.
AN/ARR-4 (XN-) XN-1 (GE) XN-2 (RCA) XN-3 (Galvin)	XANB-R-3		Airborne Communication and Navigation Receiver.
AN/ARR-5			Intercept Radio Receiver (RCM)
Radio (Remote Control - ARW)			
AN/ARW-1			Radio Control Receiving Equipment.
Magnetic Equipment (Special - ASQ)			
AN/ASQ-1	MAD, Type 6		Magnetic Airborne Submarine Detection Equipment.
AN/ASQ-1A			Same as AN/ASQ-1 except not subject to geographical limitations and include DT-3/ASQ-1A instead of DT-1/ASQ-1 and include additional unit AM-9/ASQ-1A.

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Magnetic Equipment (Special - ASQ)			
Designation	Former Navy Designation	Former Army Designation	Description
AN/ASQ-2	MAD, Type 6 (Double Unit)		Magnetic Airborne Submarine Detection Equipment.
AN/ASQ-3	MAD, Type 10		Magnetic Airborne Submarine Detection Equipment.

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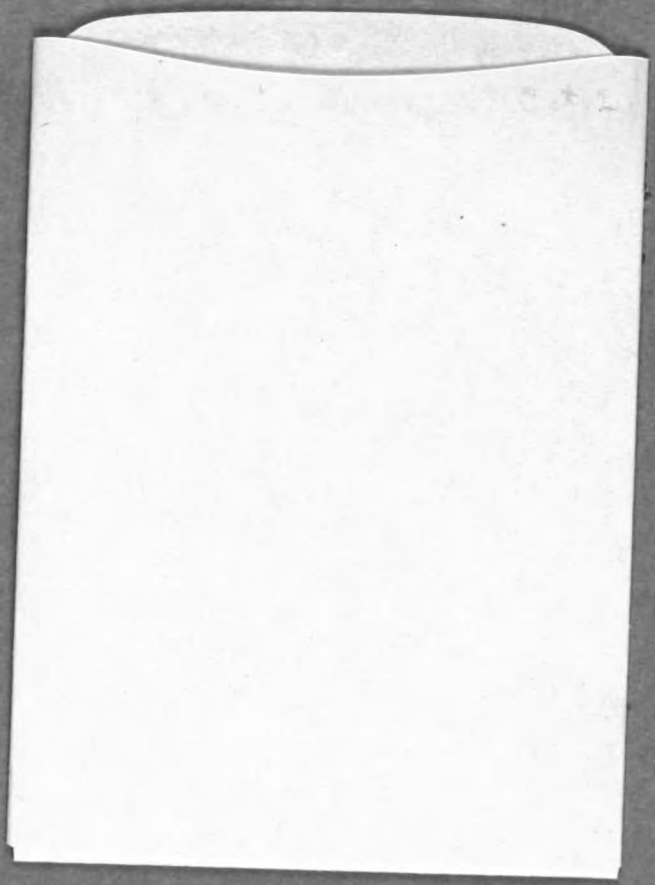

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